



# **Composition of Debris disks**

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# Contents: Composition of debris disks

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  - Collision models
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  - Dust temperatures
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  - Polarimetry
- Observations of debris disks
  - IRAS
  - Ground based
  - ISO
  - SST
- Conclusions
  - We know very little!

# What would we like to know

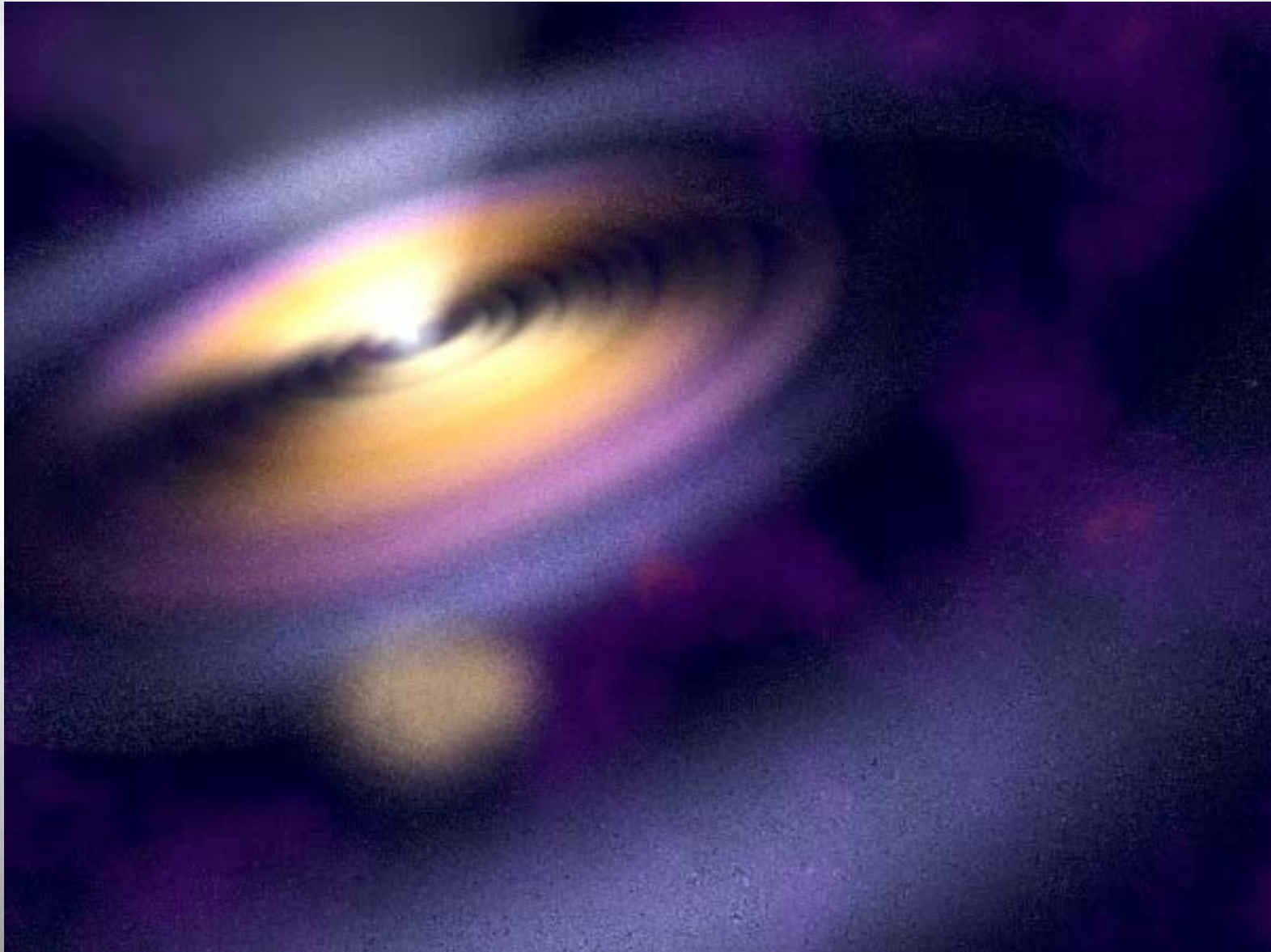
- Grain sizes
- Grain shapes
- Chemical composition
- Lattice structure (crystalline versus amorphous)
- Radial and vertical distribution

# What is different in debris disks?

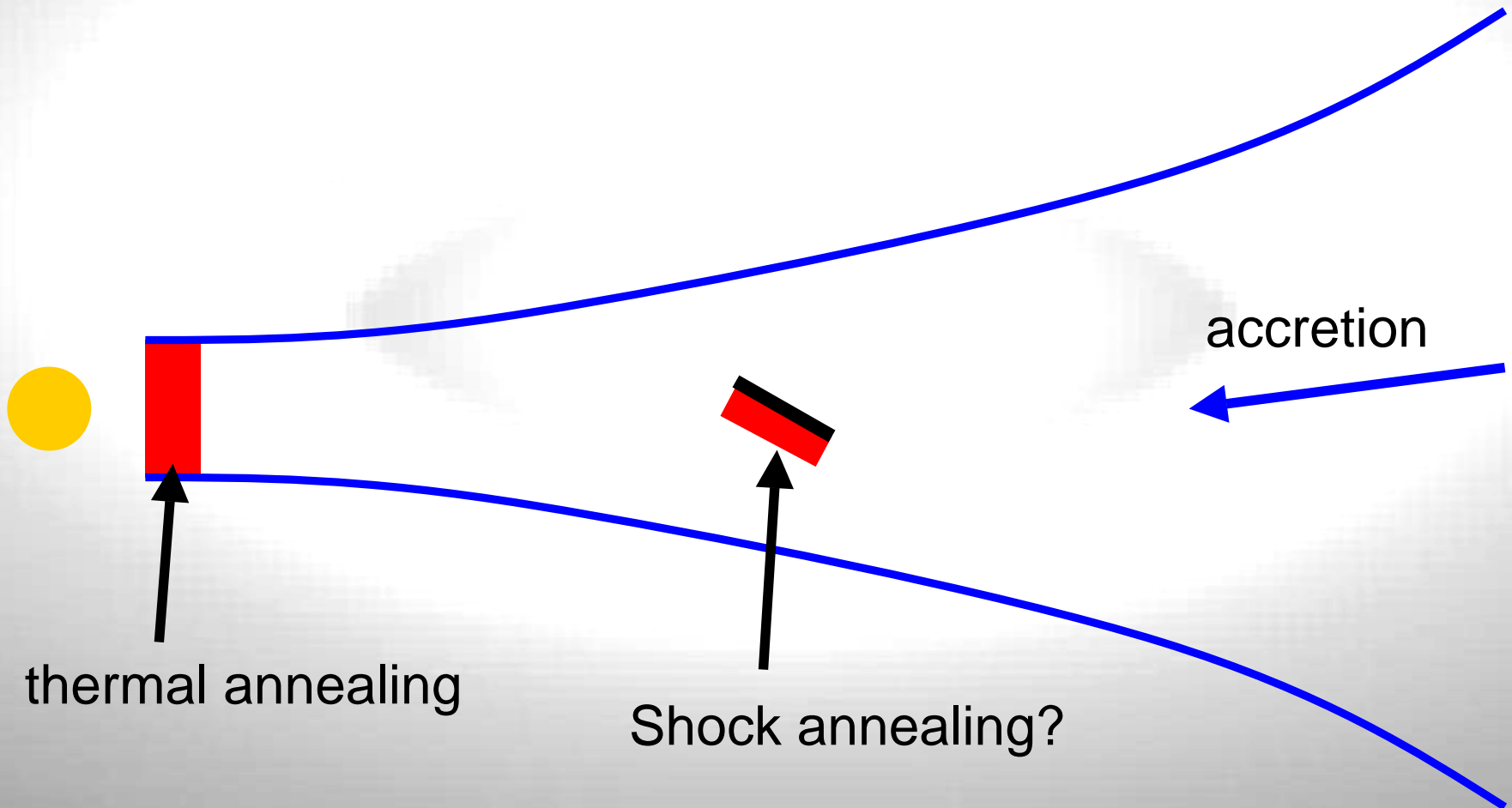
- Optically thin: At all wavelength we see every dust grain in the disk
  - => No optical depth effects
- Fainter than gas-rich disks
  - Need much better telescopes
- Small grains heavily depleted
  - Difficult to use near and mid-IR spectroscopy

# What do we expect?

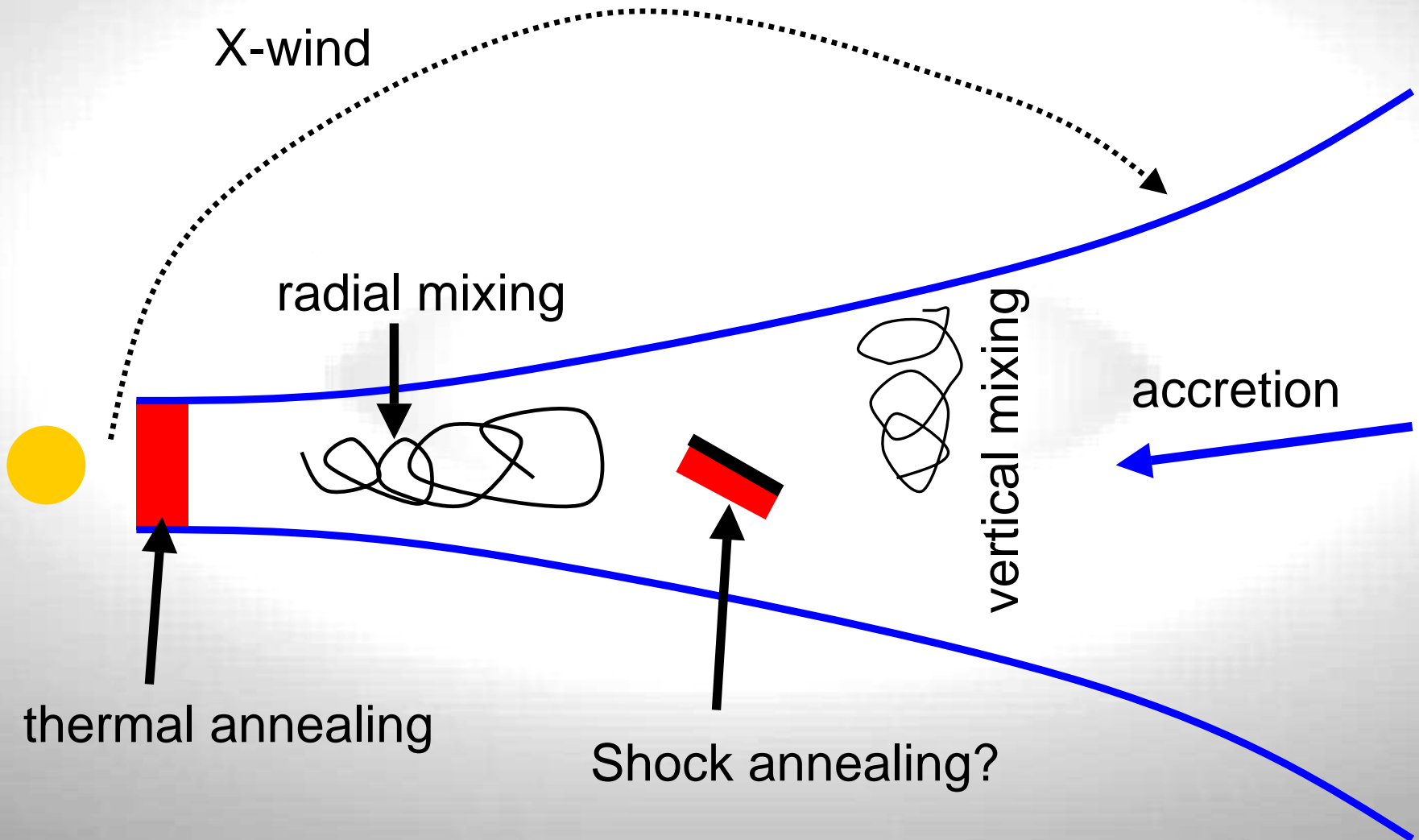
Assumption: Debris disks are like the solar system



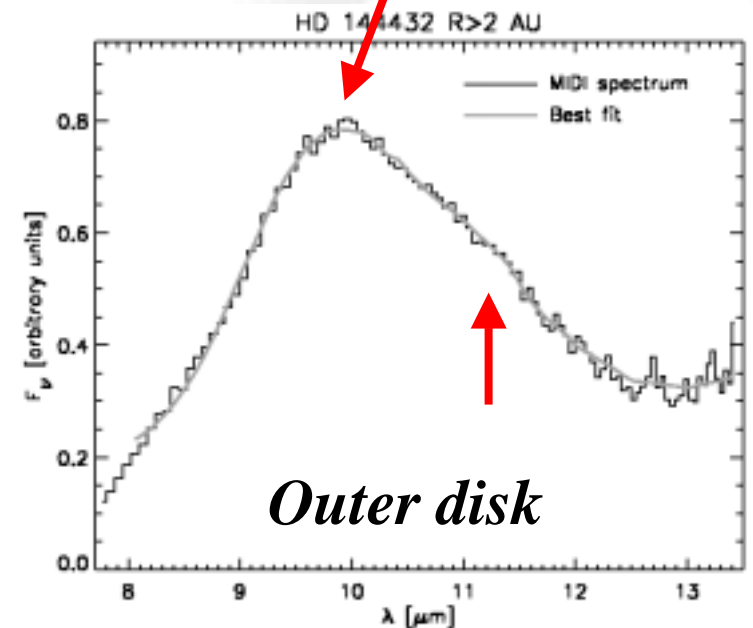
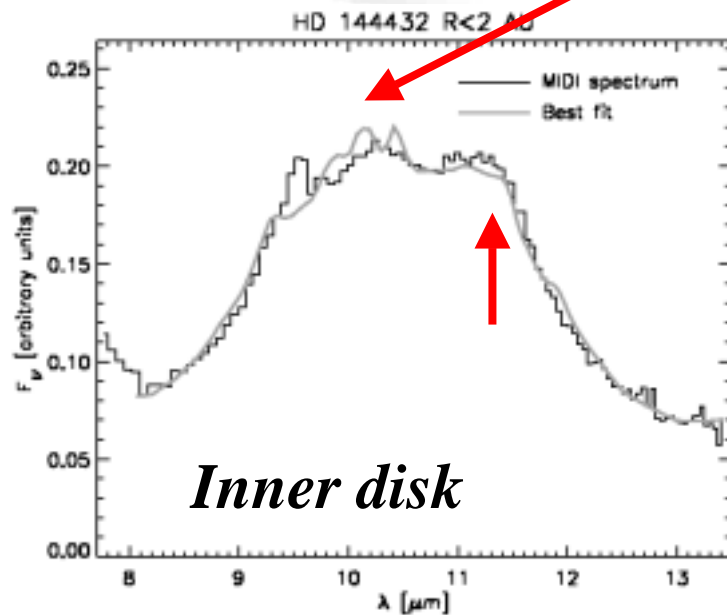
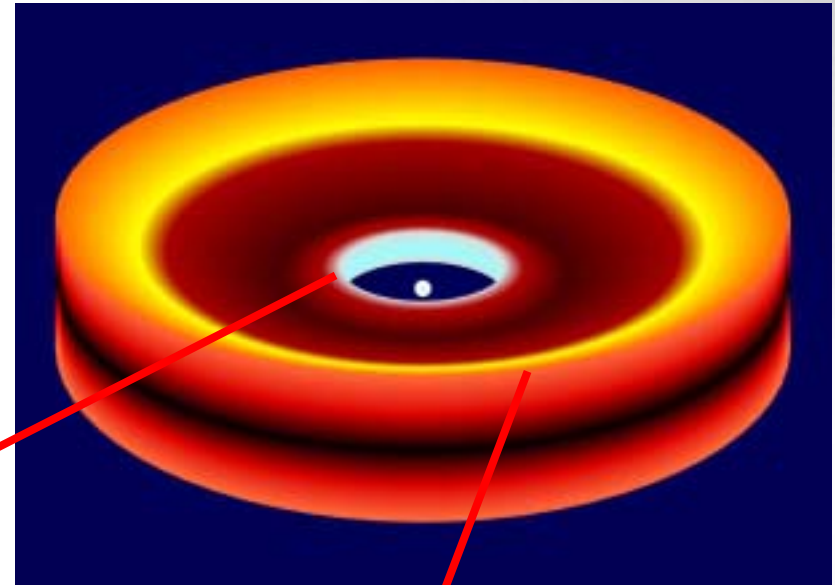
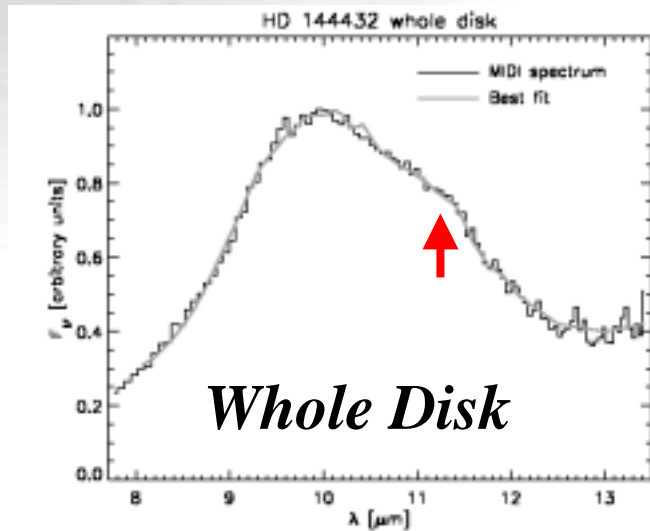
# Crystallization and Mixing



# Crystallization and Mixing

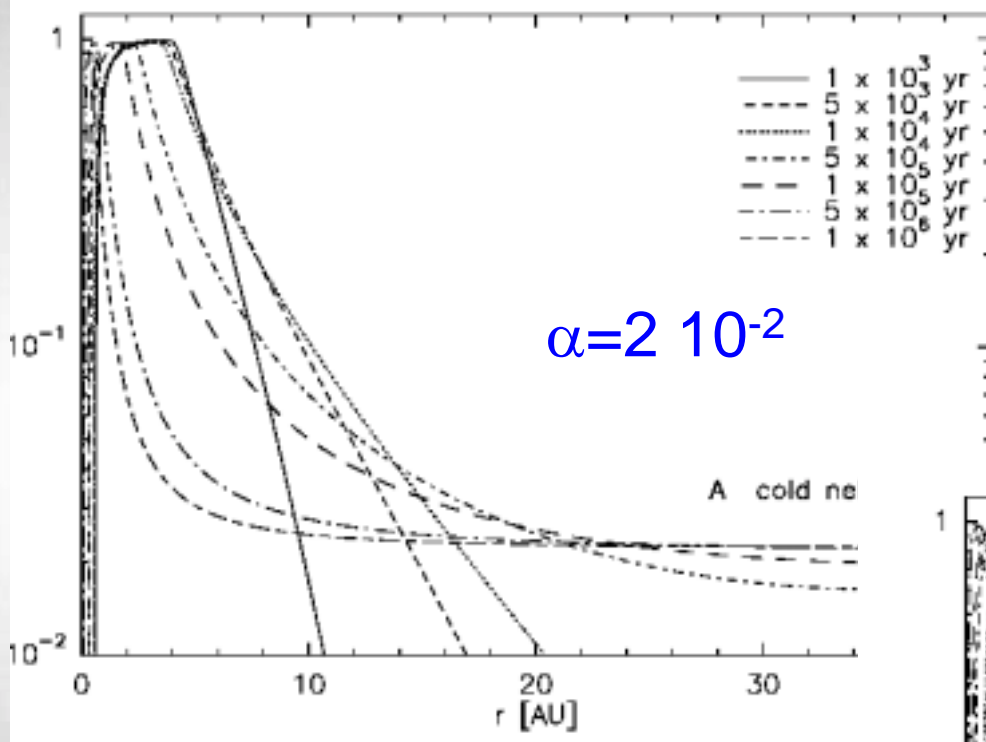


# Spatially resolved spectroscopy

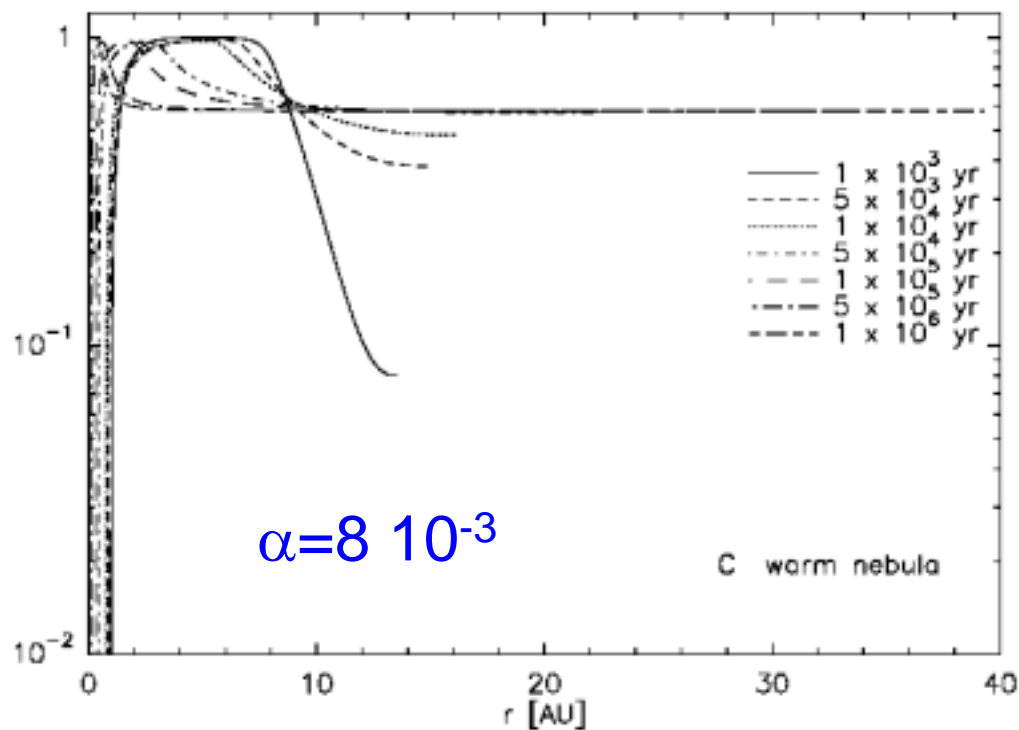




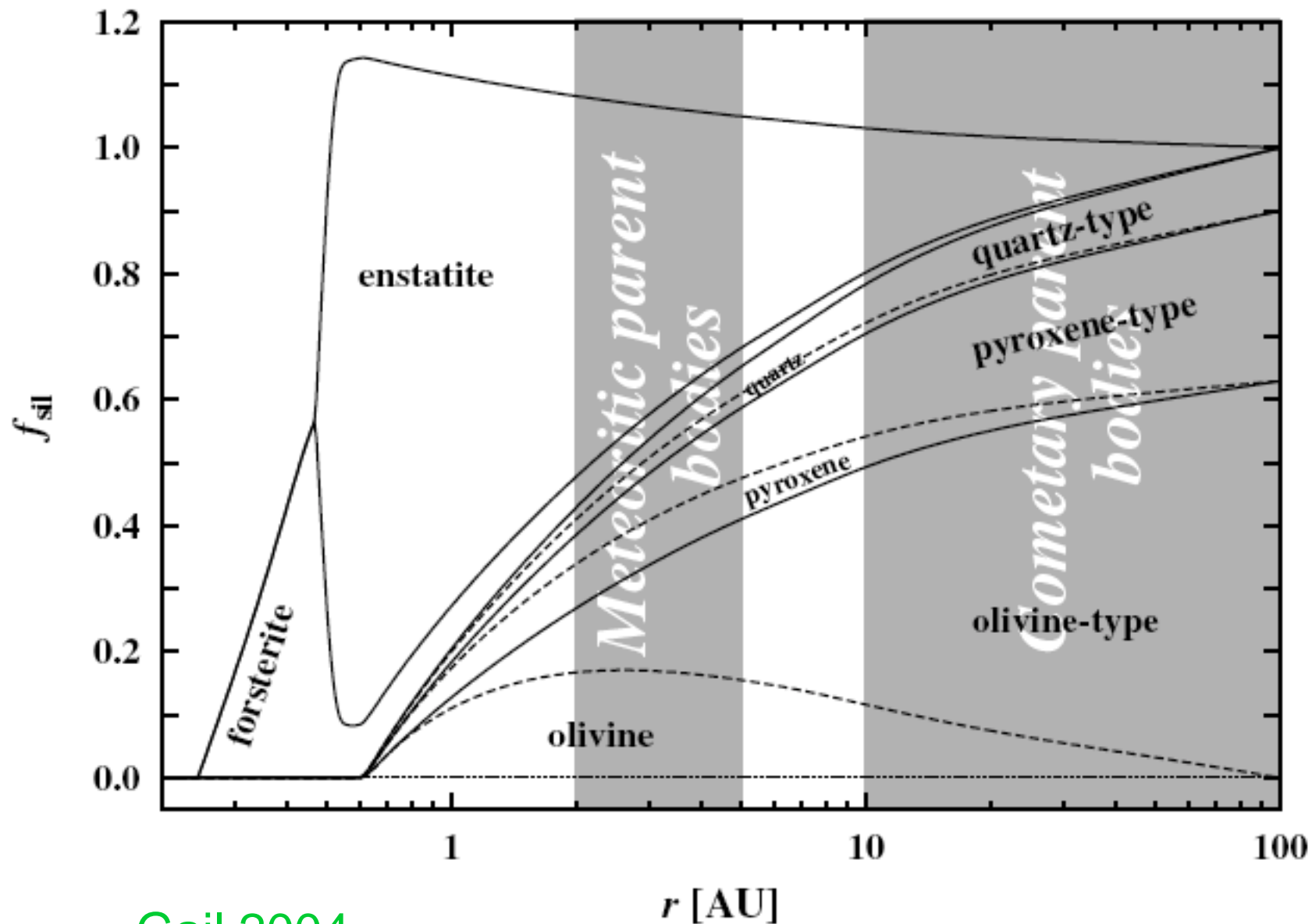
# Radial mixing models

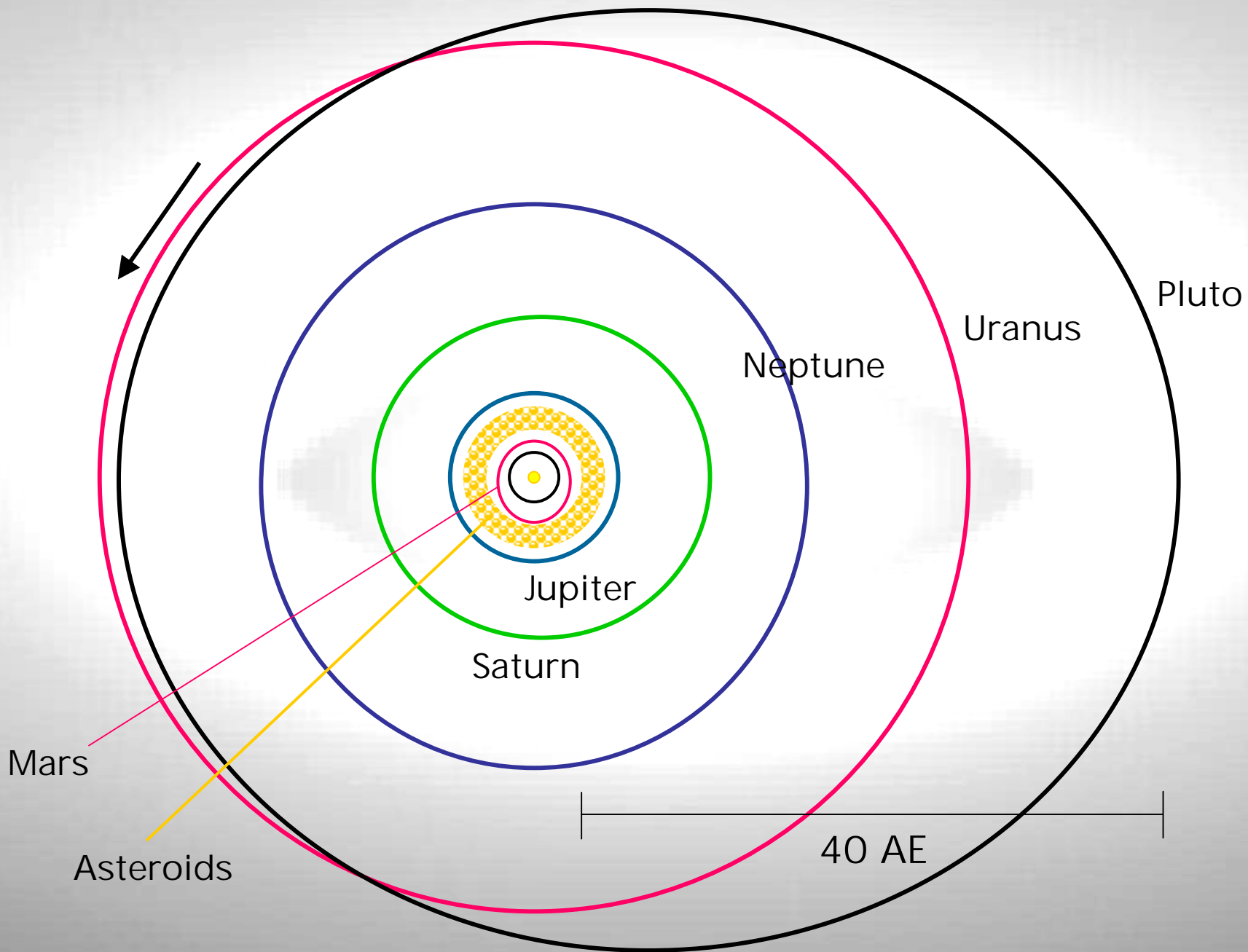


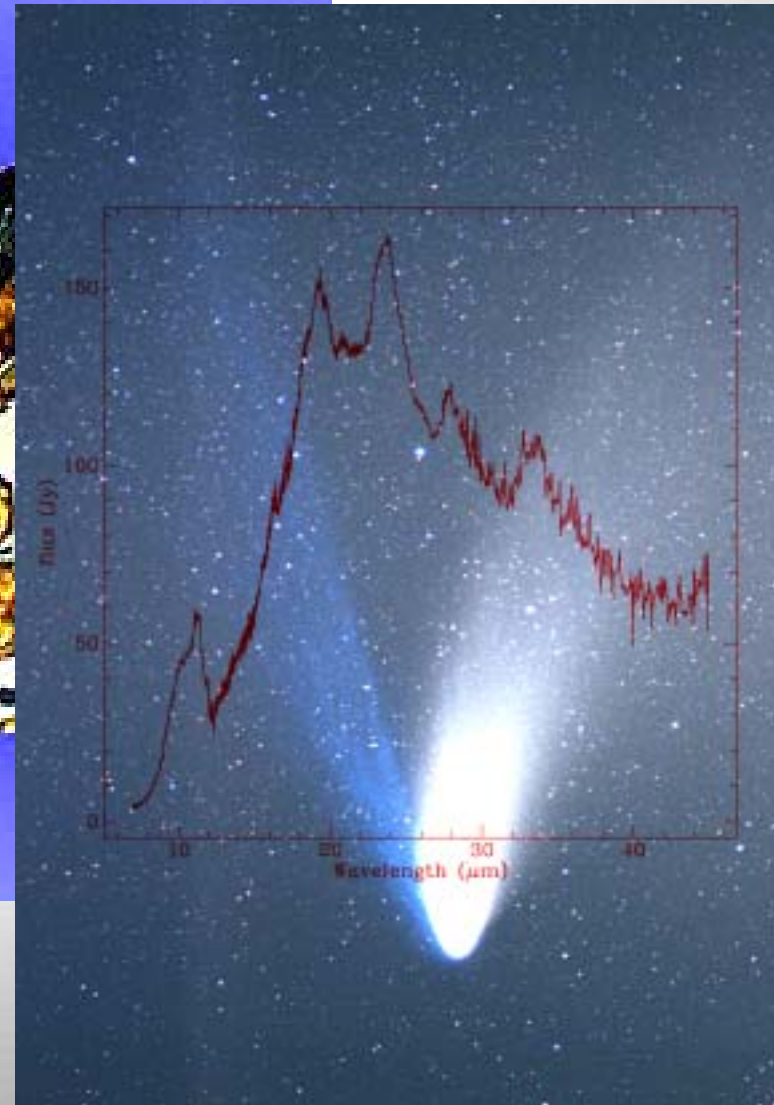
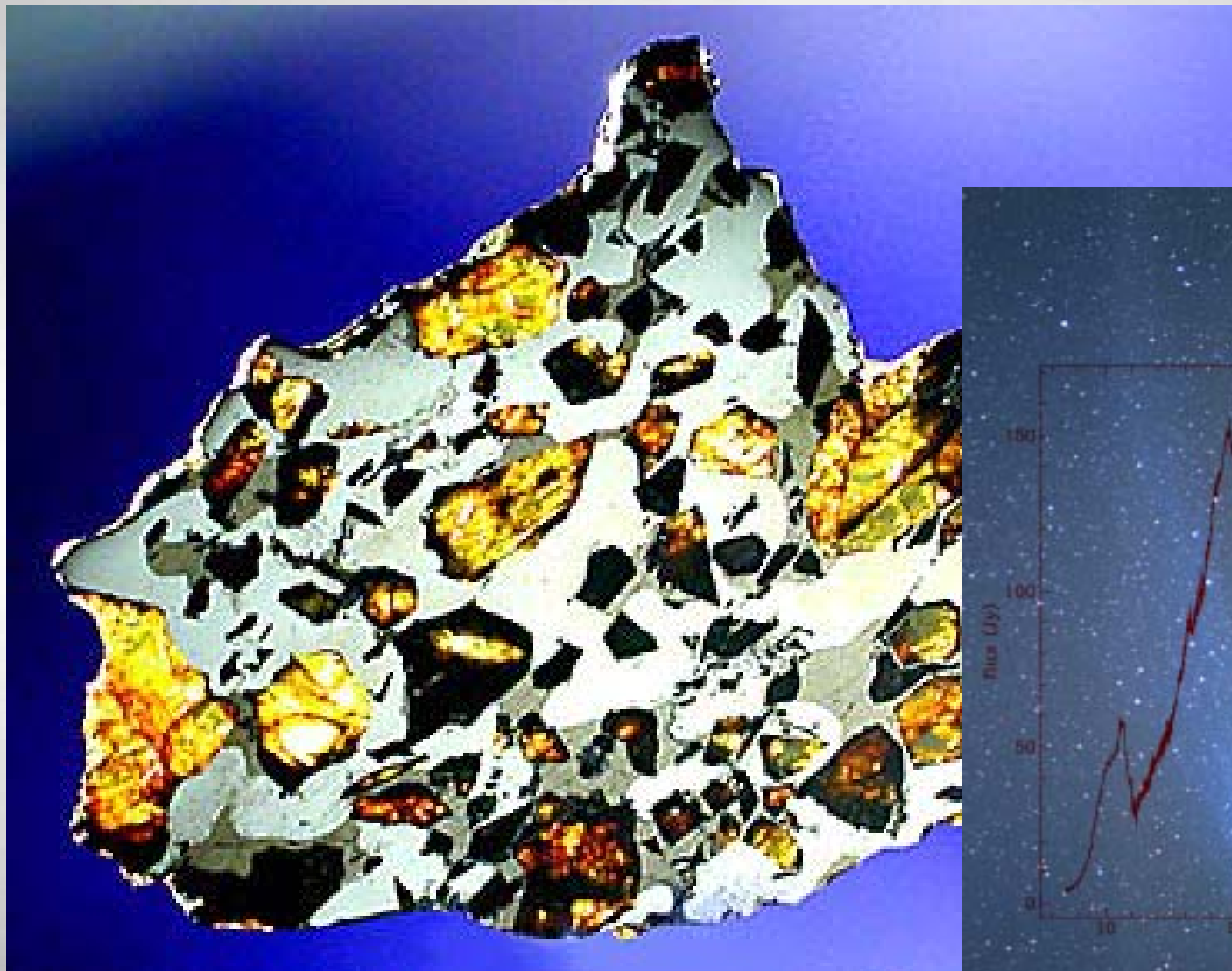
Brokelee-Morvan et al 2002



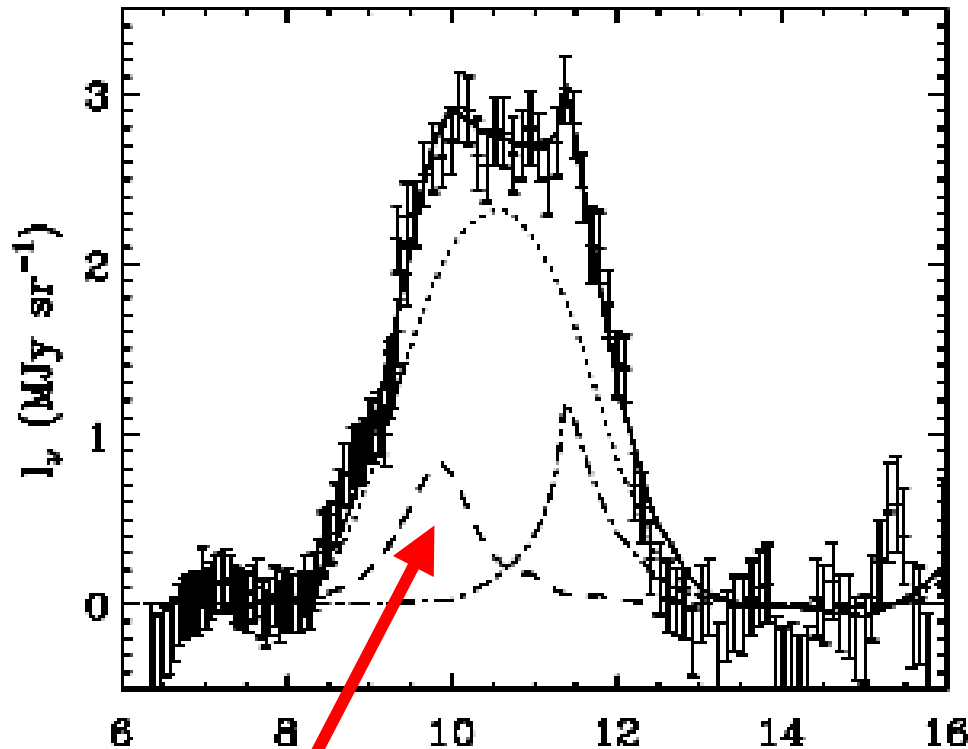
# Radial Mixing Models







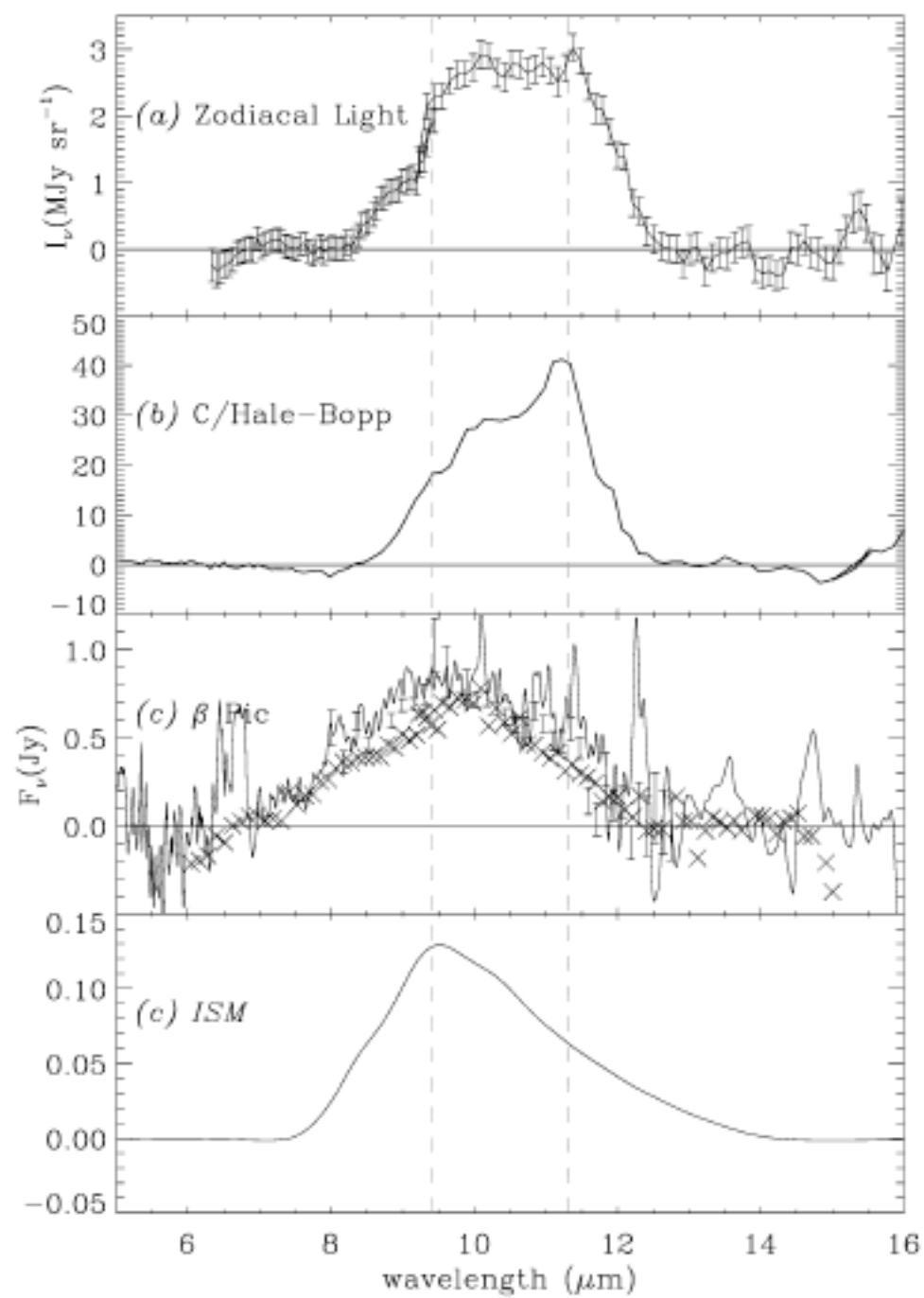
# Zodiacal light feature



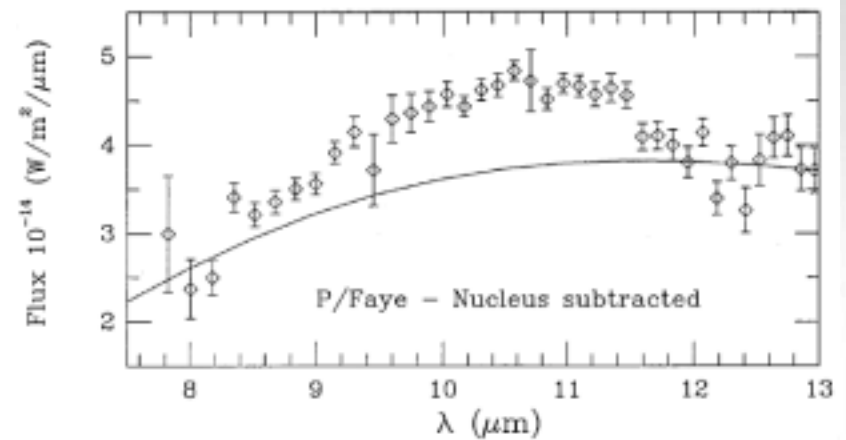
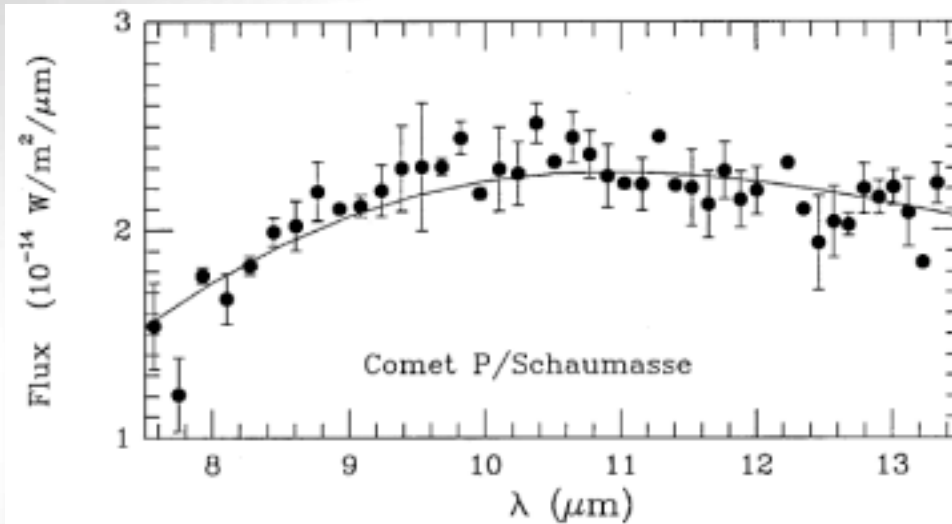
Montmorillonite

- Zodiacal dust is made of particles with sizes 10-100um
- Contains hydrous silicates (altered by liquid water)
- Feature shape different from comets

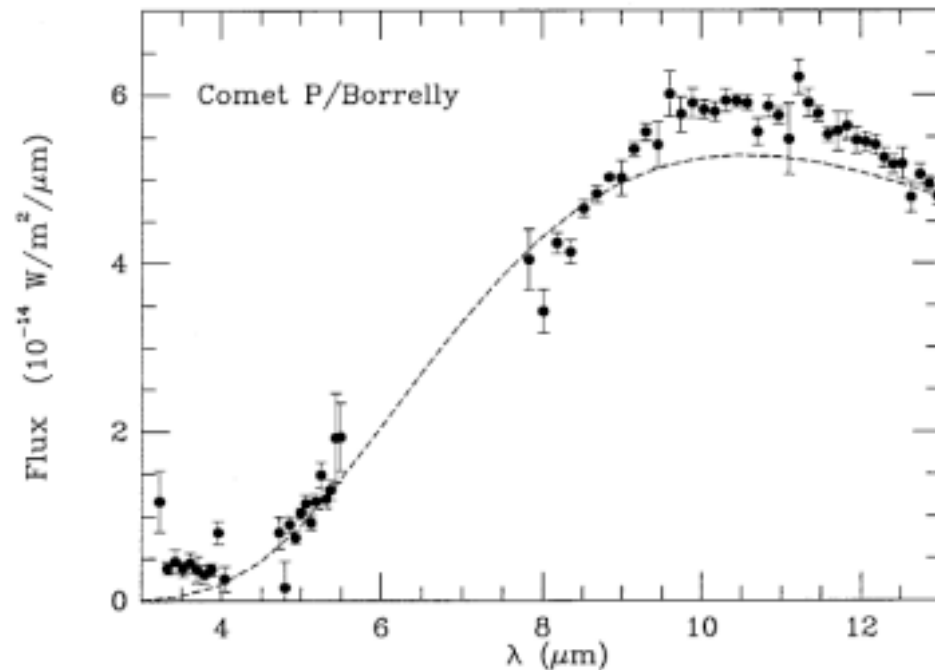
Reach et al 2003



# Short period comets: weak or no feature



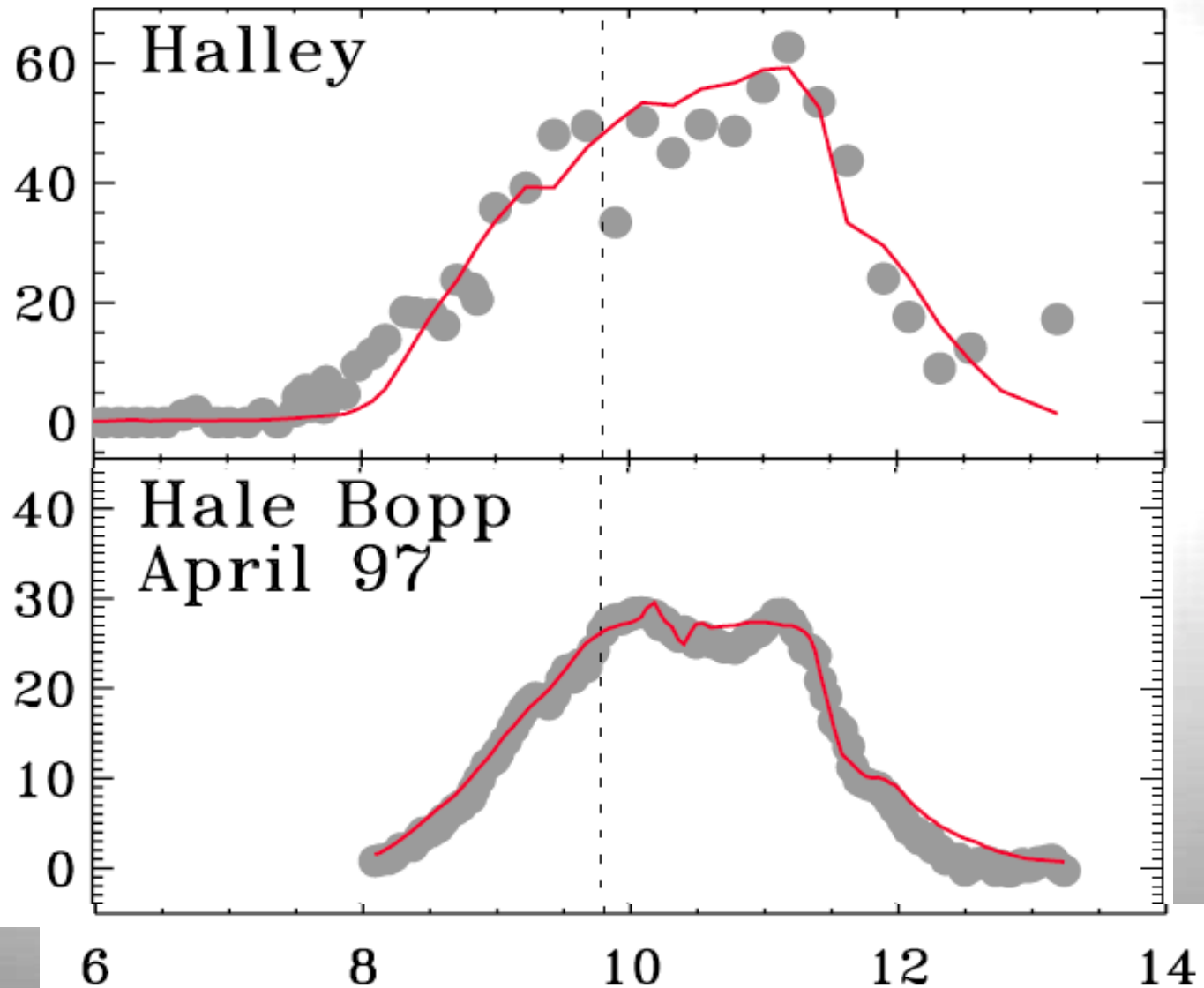
Feature/continuum < 1



Hanner et al 1996

# Long period comets: strong features

Feature/continuum ~ few





# Grain size limit due to blow-out

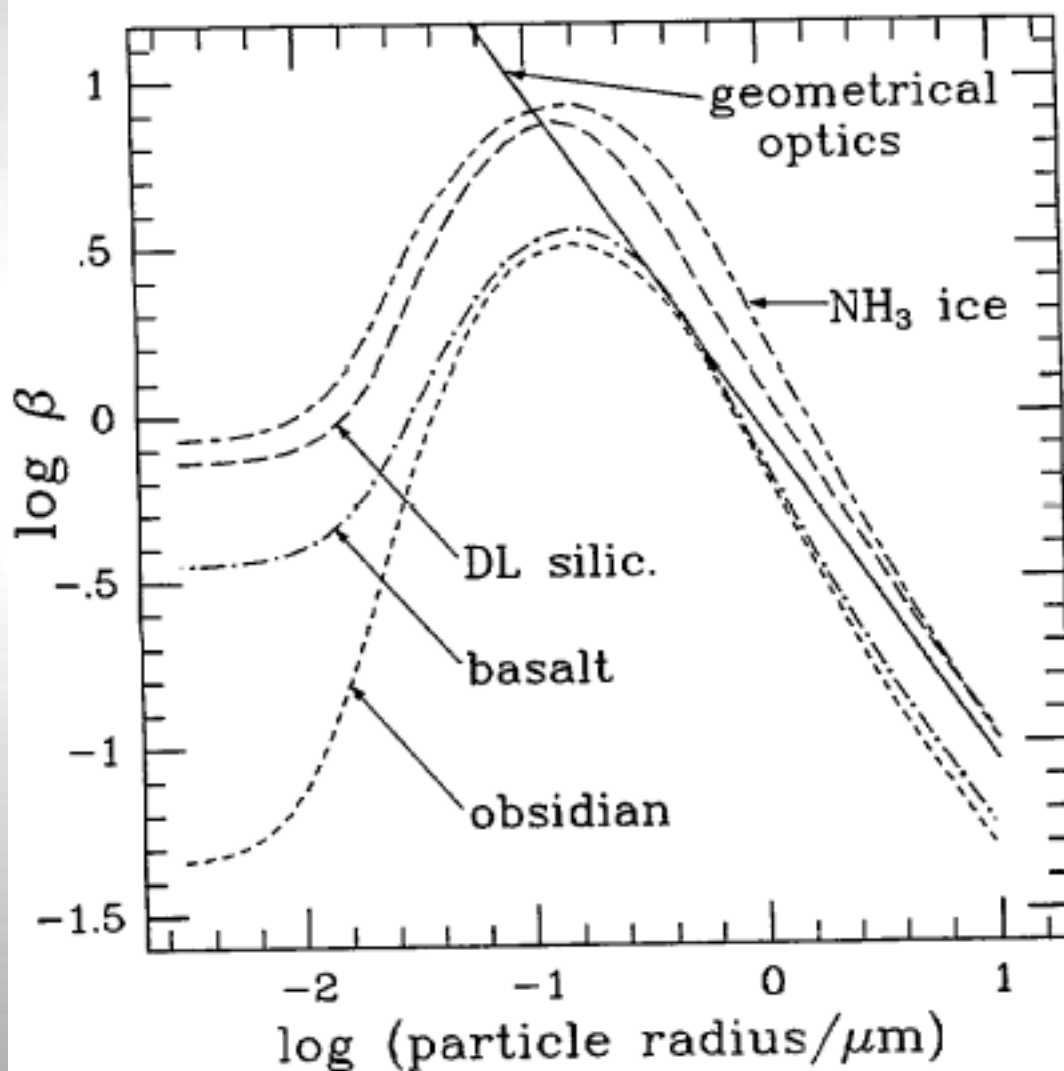


FIG. 1.—The ratio of the radiation pressure force to the gravitational attraction for spherical particles of different compositions vs. particle radius.

- Radiative blowout provides a lower limit to grain sizes
- Smaller grains are only present for a Kepler time after production
- Smallest grains are not blown out!

Artymowicz 1988

# Summary of expectations

- Grains like cometary IDPs: Porous aggregates
- Most grains larger than the blowout size
- Amorphous silicates, maybe small fraction of crystalline silicates
- Crystalline could be primordial, or produced by comets destroyed very close to the star.
- Systems with warm dust may have asteroidal dust: Highly crystalline, contains hydrous silicates
  - Alternative: Cometary dust heated close to the star

# Diagnostic methods

- Distance- $T_{\text{grain}}$  relation
  - grains size
- Spectral energy distribution
  - Grain size distribution, especially for radially constrained disk
- Spectroscopy
  - Composition, grain sizes and shapes
- Polarimetry
  - Grain sizes, material possibly porosity
  - but requires angular coverage

## Distance- $T_{\text{grain}}$ relation

If source size and dust temperature are known, distance can be calculated.

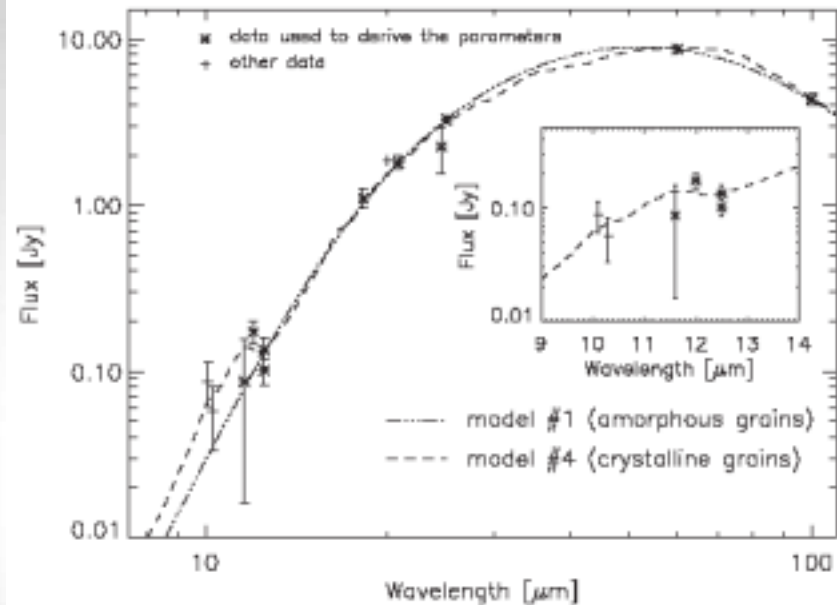
For resolved sources, this leads to grain sizes of a few to hundred microns (Backman & Paresce 1993)

New results on Vega imply very small grains in outer disk

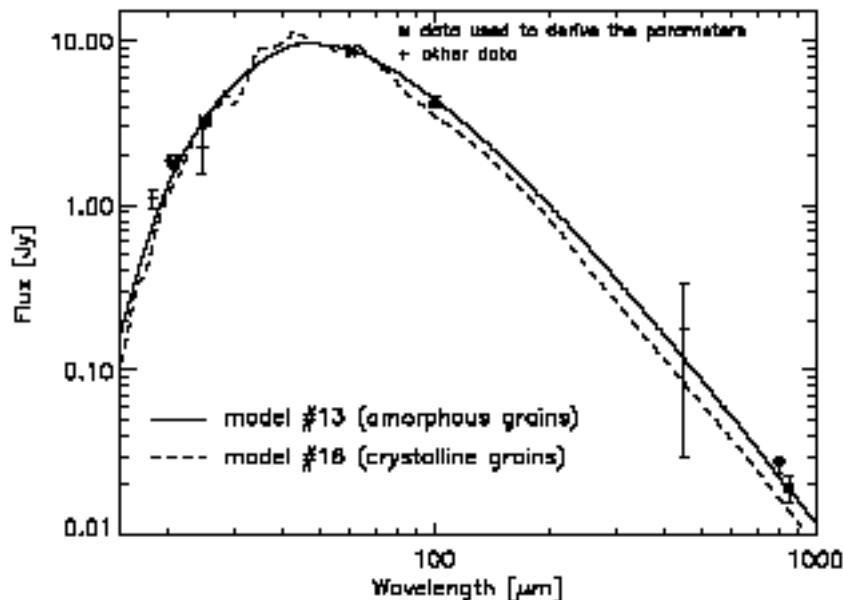
## SED fitting

- Use a dust model to fit the entire SED of a debris disk
- Try to determine the parameters of the dust like
  - Size distribution ( $a_{\min}$ ,  $a_{\max}$ , power law)
  - Material or materials (core-mantle grains)
  - Porosity
- Difficult when radial distribution is not known -> Ring sources

# SED fitting example: HR 4796A



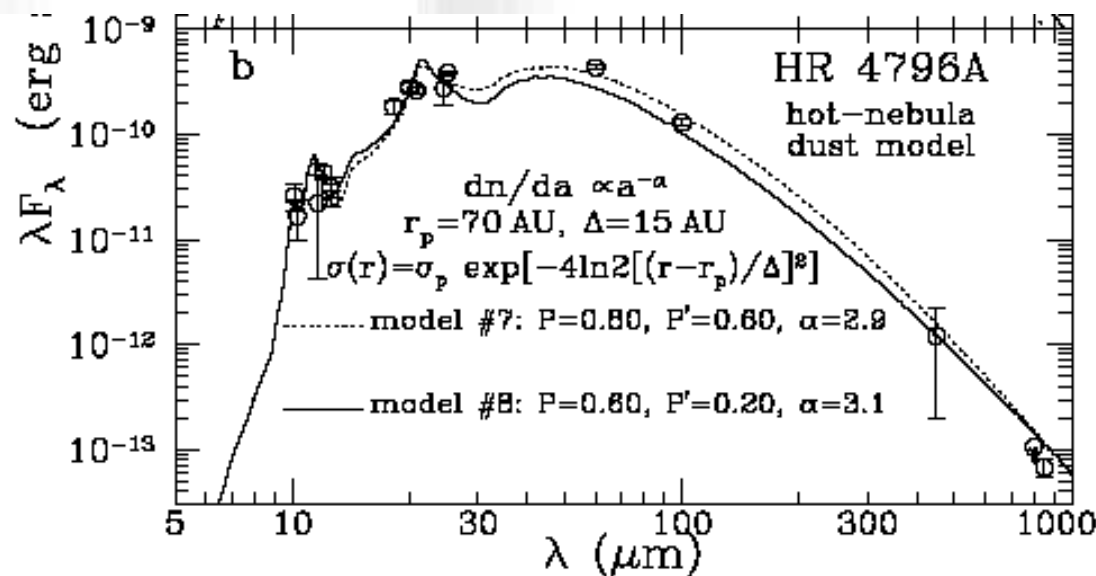
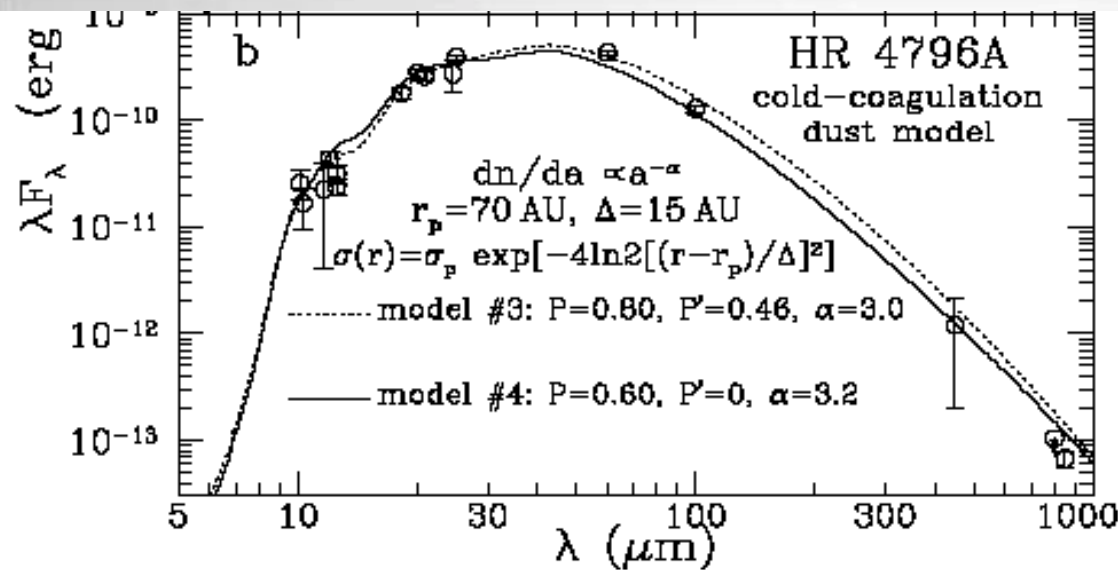
- Augereau et al 1999
  - Cold component at 70AU, amorphous, porous 60%, >10micron
  - Warm component at 9AU, crystalline, porous 90%



# SED fitting example: HR 4796A

Li & Lunine 2003

- Good fit with single component of porous (90%) dust. Silicates can be either crystalline or interstellar
- No evidence for hot component



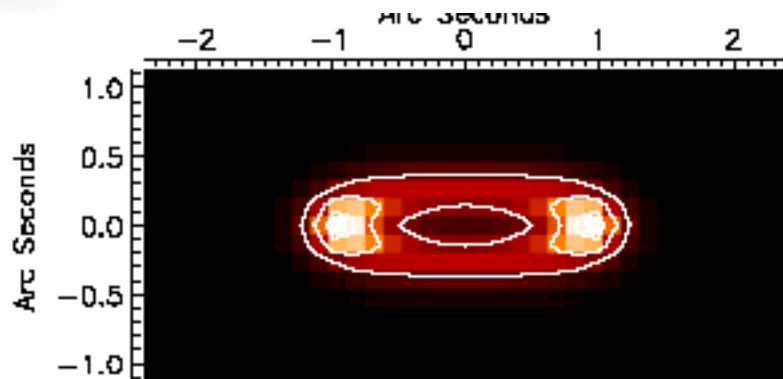
# SED fitting: Parameter comparison

Model	Sizedist	Spatial	Material	Scattering Images	Thermal images		
A et al	10-143um $\alpha=3.5$	2x power law	Amo+Org+Ice Cry	1.1um K band	20.8 AU		
L&L prim	1um-1cm $\alpha=2.9$ P=0.95	Gauss	Amo+Org+Ice	N/A	N/A		
L&L proc	1um-1cm $\alpha=2.6$ P=0.95	Gauss	Cry+Org+Ice	N/A	N/A		

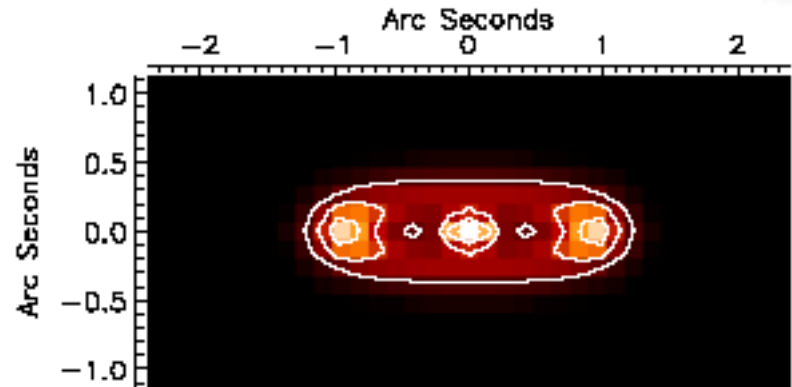


# Fitting thermal and scattering images

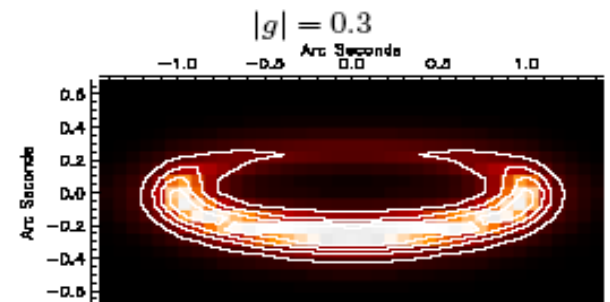
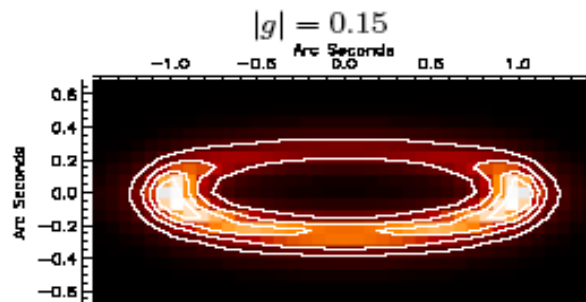
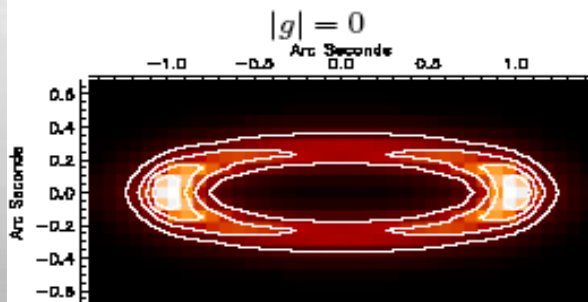
Augereau et al 1999



Cold annulus alone ( $\simeq 1.6$  Jy)



Cold annulus + hot dust population ( $\simeq 0.2$  Jy)

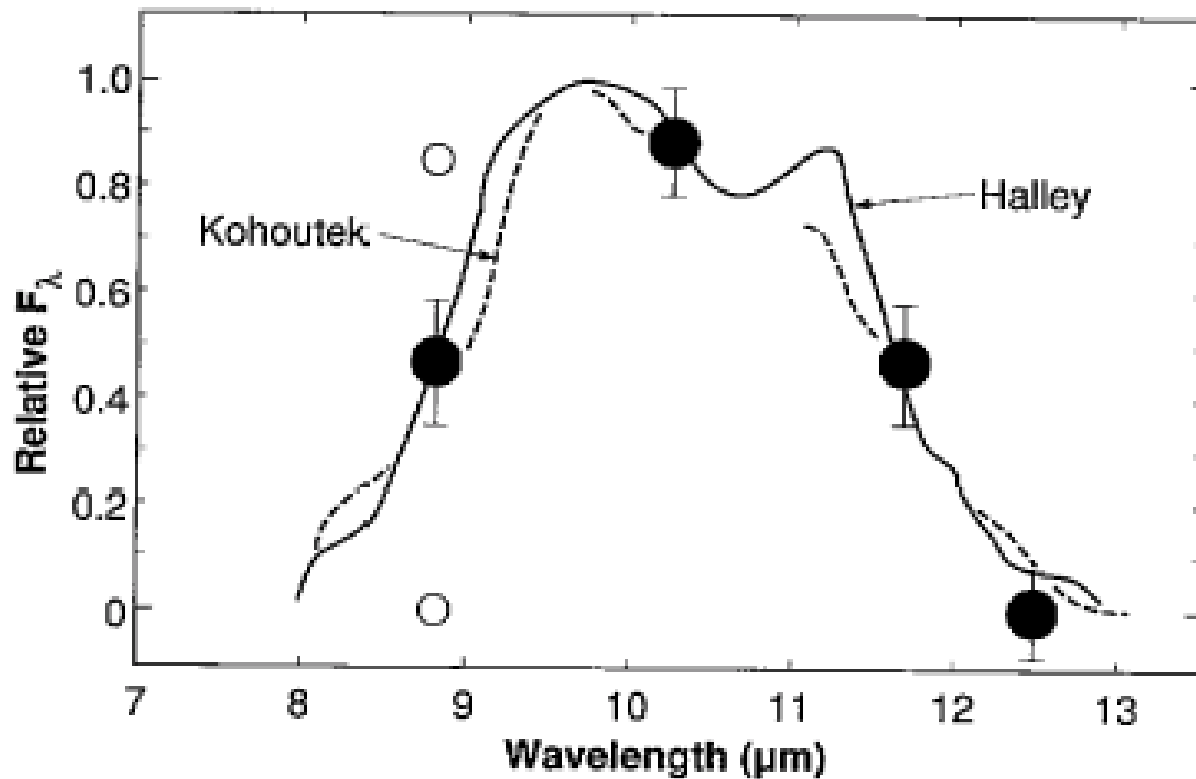


$$g < 0.15$$

# IR Spectroscopy

- Infrared emission feature reveal grain sizes, composition, and shape
- Problems
  - Emission features require grains in or close to Rayleigh limit, but Vega-like disks are dominated by large grains
  - Dust mostly from Kuiper-Belt like regions: features may be weak anyway
  - Low dust temperature select against 10 $\mu$ m emission

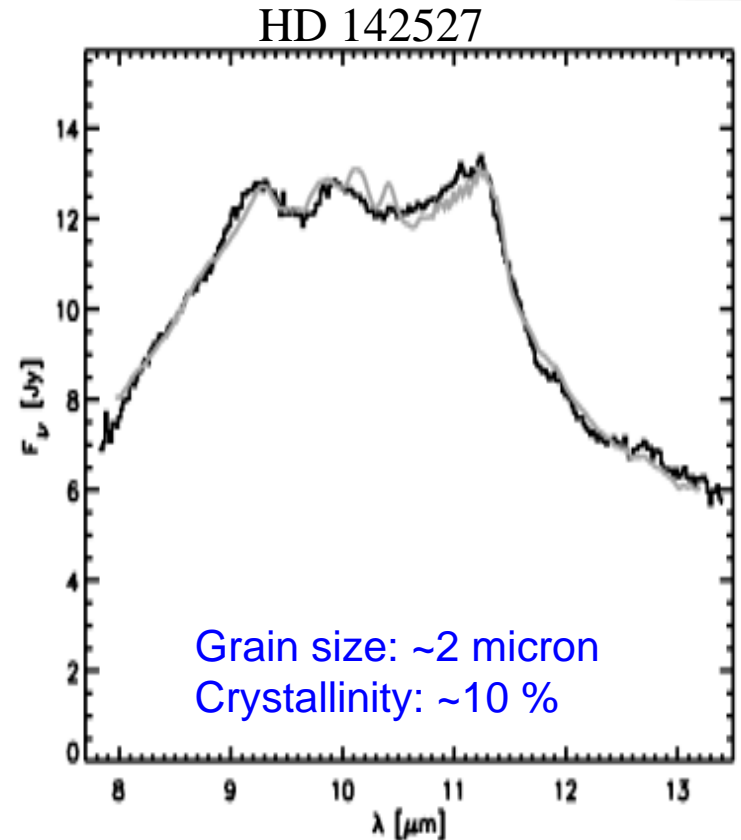
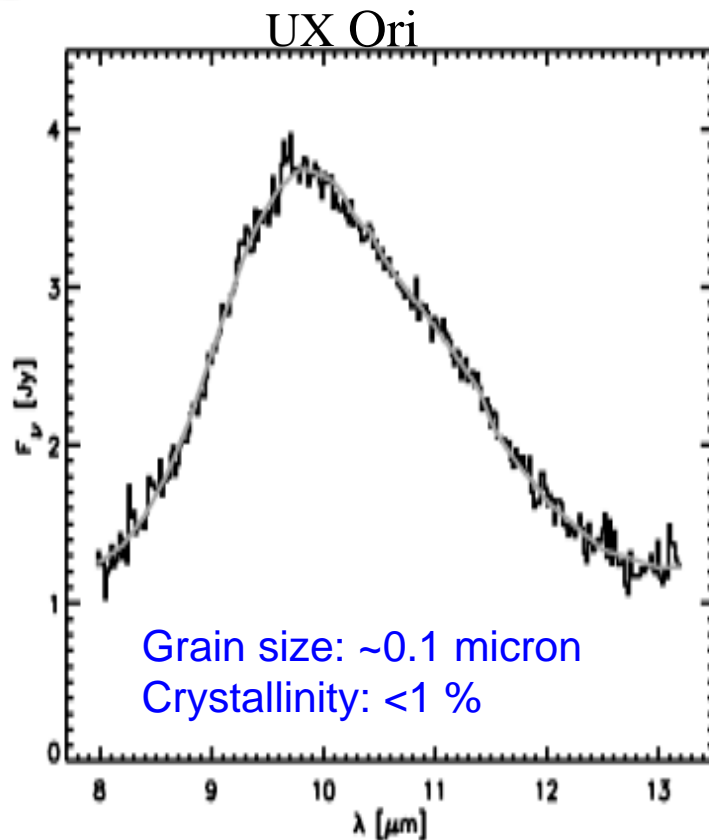
# The 10 micron spectrum of beta Pic



Telesco and Knacke, 1991

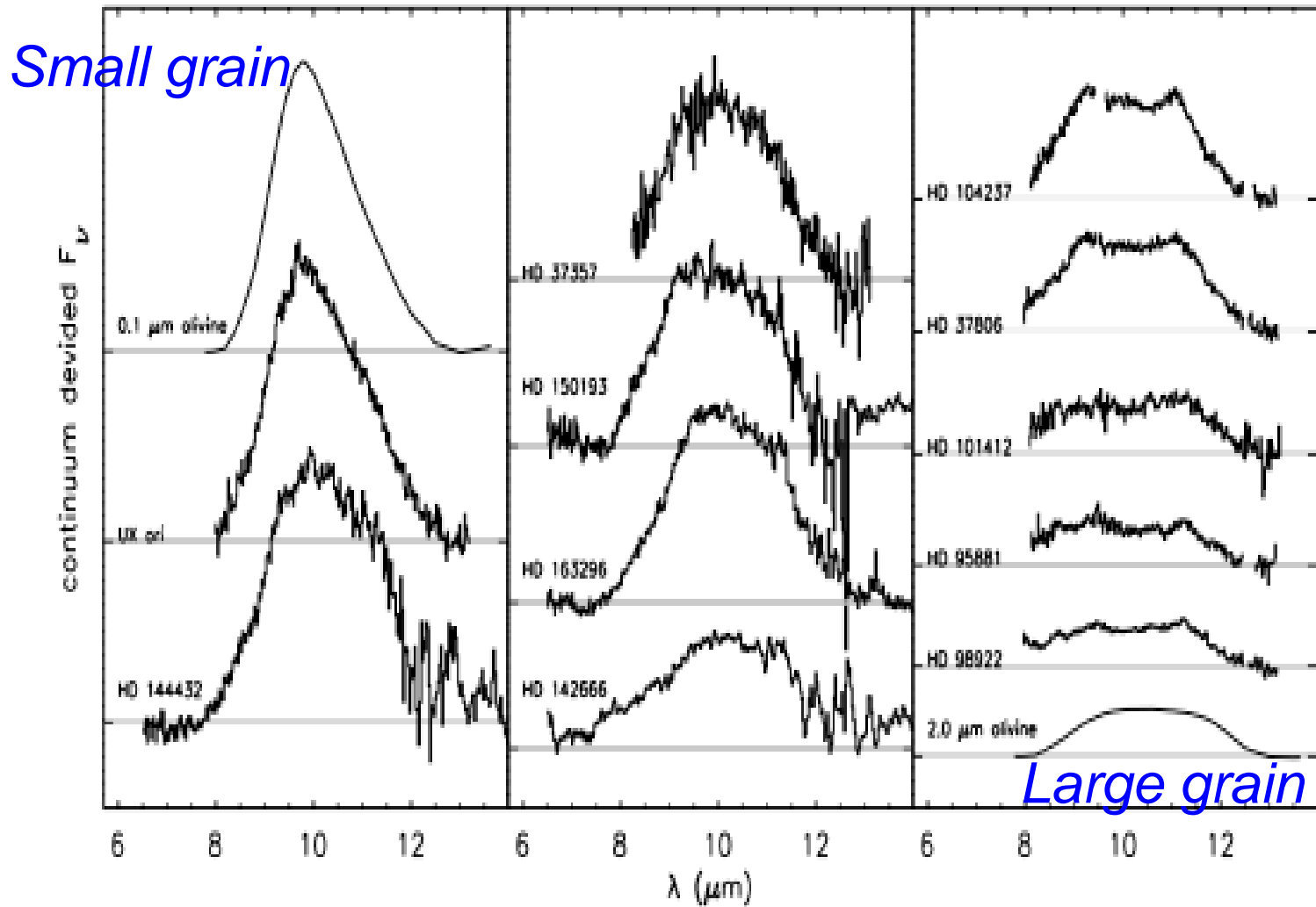
# Dust processing as seen in 10 $\mu$ m spectra

Pre-processed spectra (see also Figure 10 in Min et al. 2005)



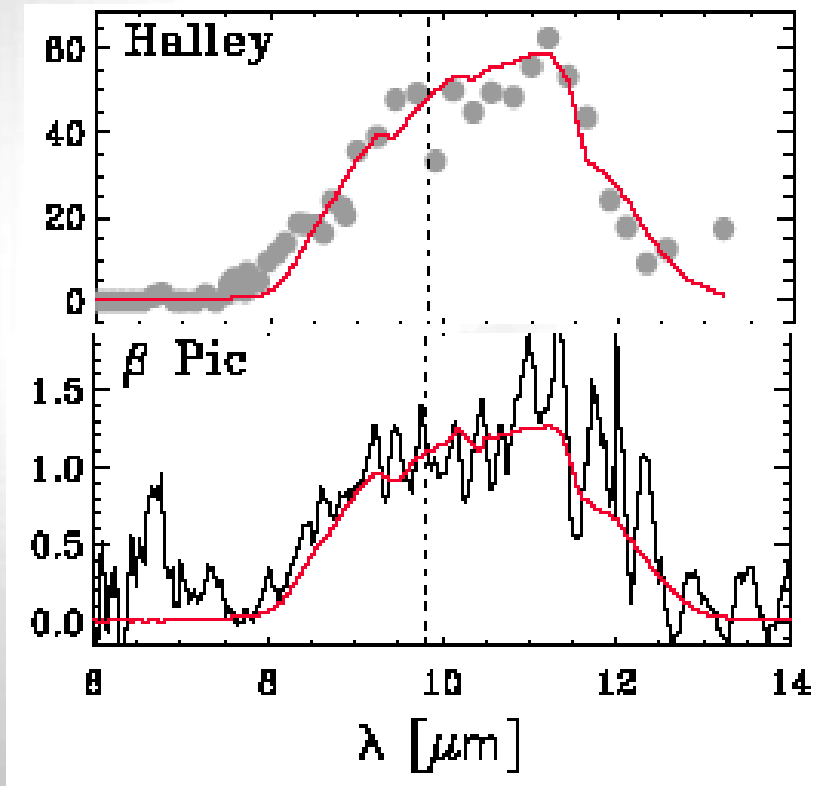
Compositional fits: M. Min

# Evidence for grain growth



# Composition derived from 10um spectra

- $\beta$  Pic spectrum looks similar to Halley

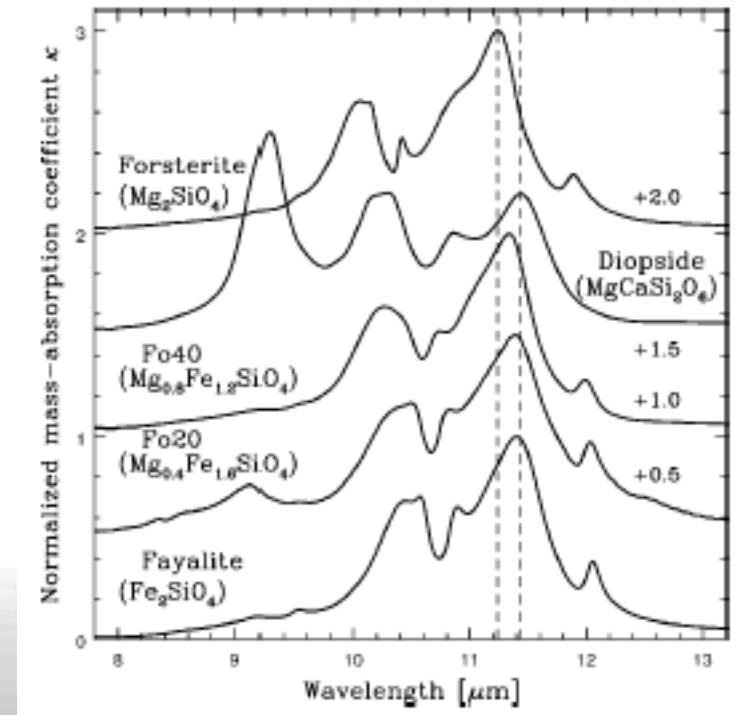
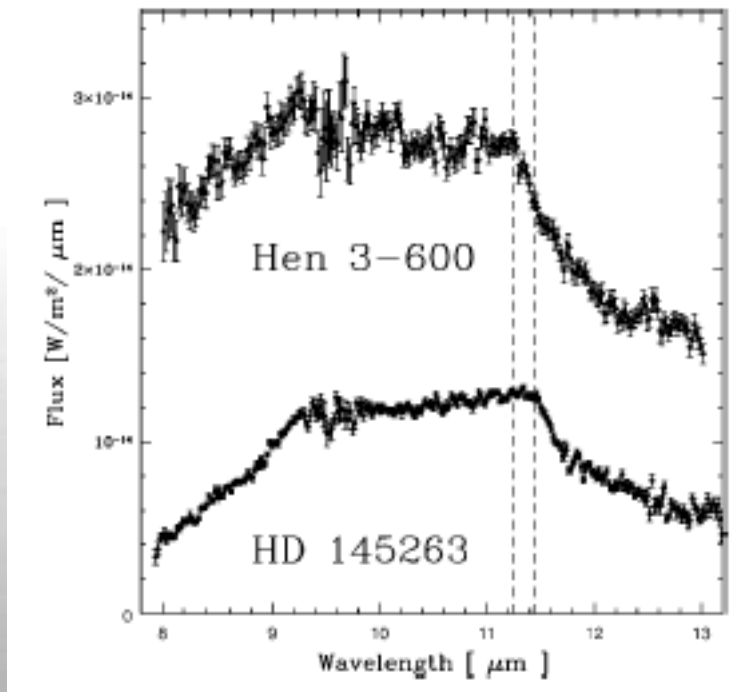


Object	$M_{2.0\mu\text{m}}/M_{0.1\mu\text{m}}$	$M_{\text{fo}}/M_{\text{sil}}$
$\beta$ Pic	3.9	0.16
Halley	2.73	0.22

Bouwman et al 2001:

# Composition of HD 145263

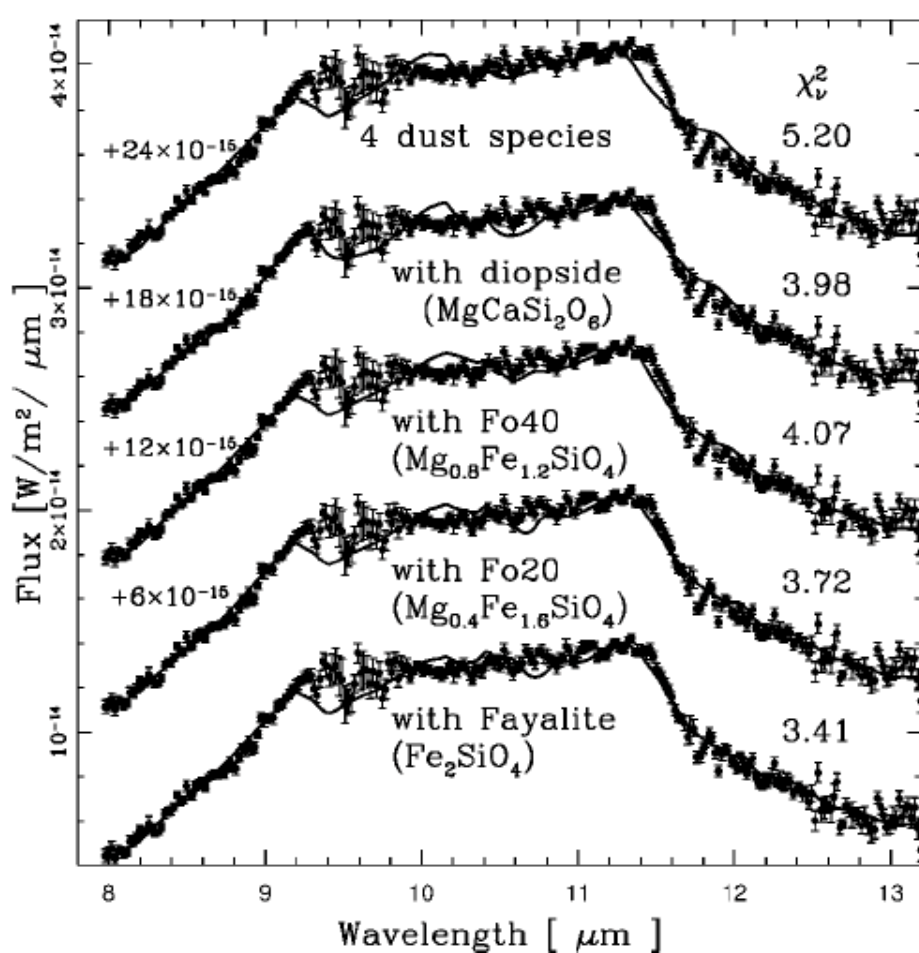
- F0V star,  $f_{\text{dust}} = 0.02$ , 8-10 Myr



Honda et al 2004

# HD 145236

- Best fit contains Fayalite
- But grain size effects may also be responsible

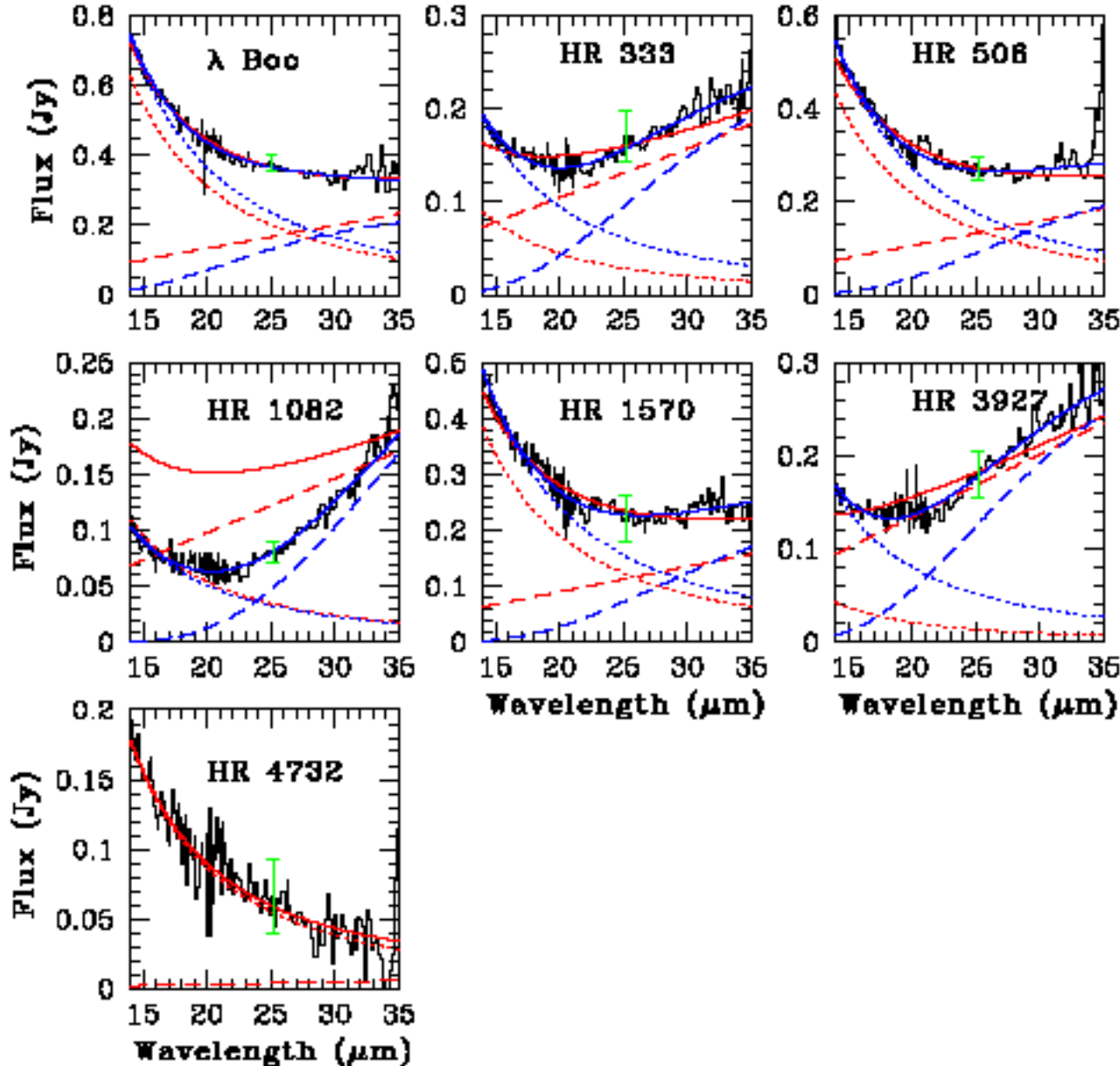


COMBINATION OF DUST SPECIES AND REDUCED  $\chi^2$  ( $\chi_r^2$ ) FOR THE BEST FIT

0.1 $\mu\text{m}$	2.0 $\mu\text{m}$								
Amorphous Olivine	Amorphous Olivine	Forsterite	Silica	Diopside	Fo40	Fo21.8	Fayalite	$\chi_r^2$	
✓	✓	✓	✓					5.20	
✓	✓	✓	✓	✓				3.98	
✓	✓	✓	✓		✓			4.07	
✓	✓	✓	✓			✓		3.72	
✓	✓	✓	✓				✓	3.41	



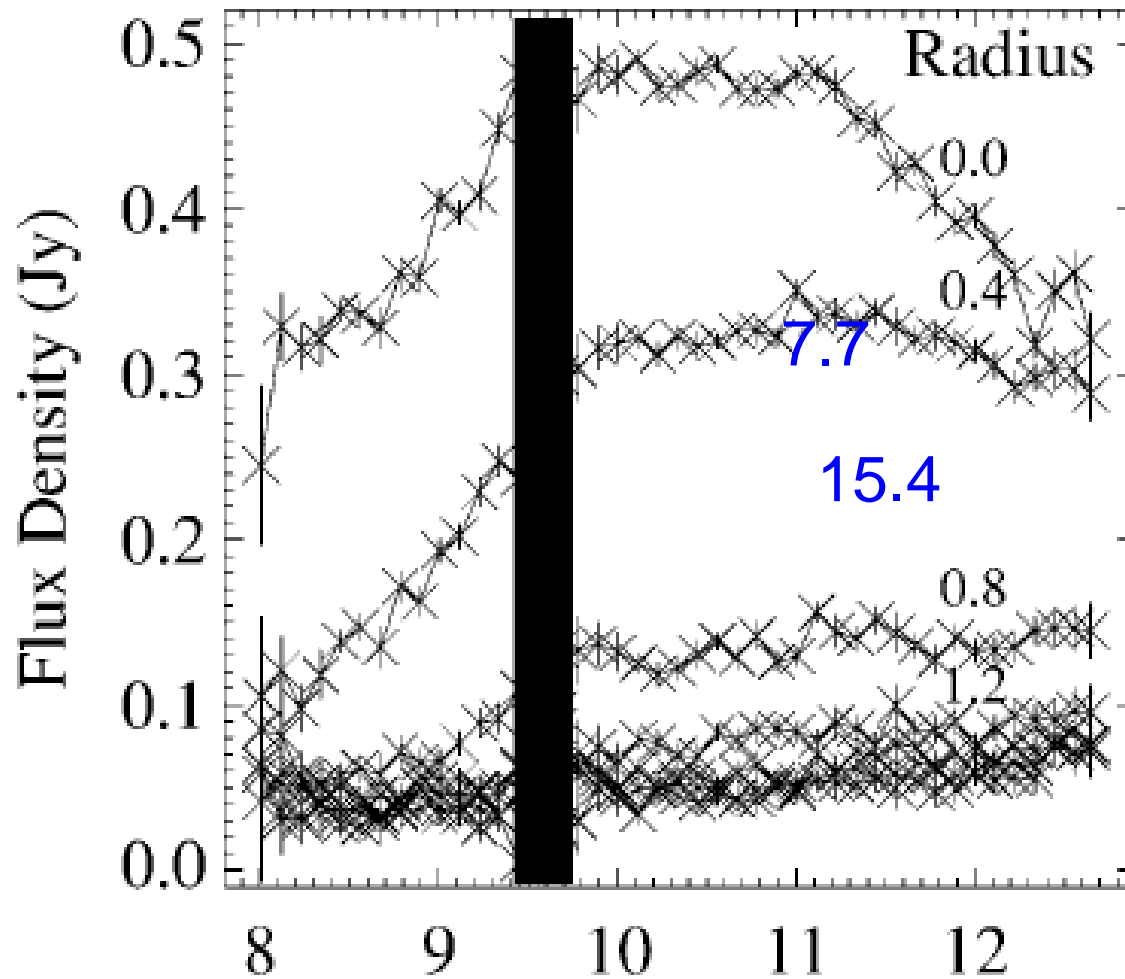
# SST observations of debris disks



- No features at wavelength >10μm.
- Large grains only
- Inner truncation between 10 and 54 AU

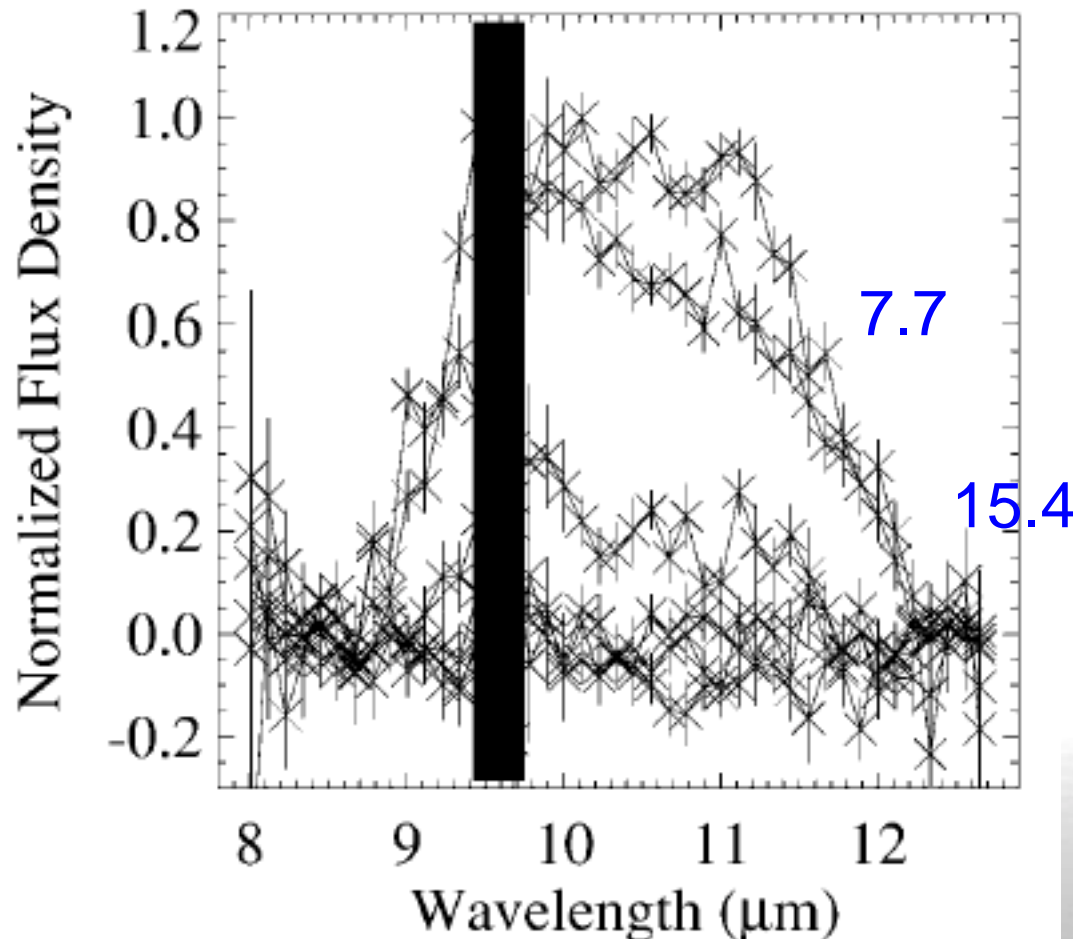
Jura et al 2004

## $\beta$ Pic: Grain composition as function of distance



Keck LWS  
Observations  
Spectra at different  
distances of the star.

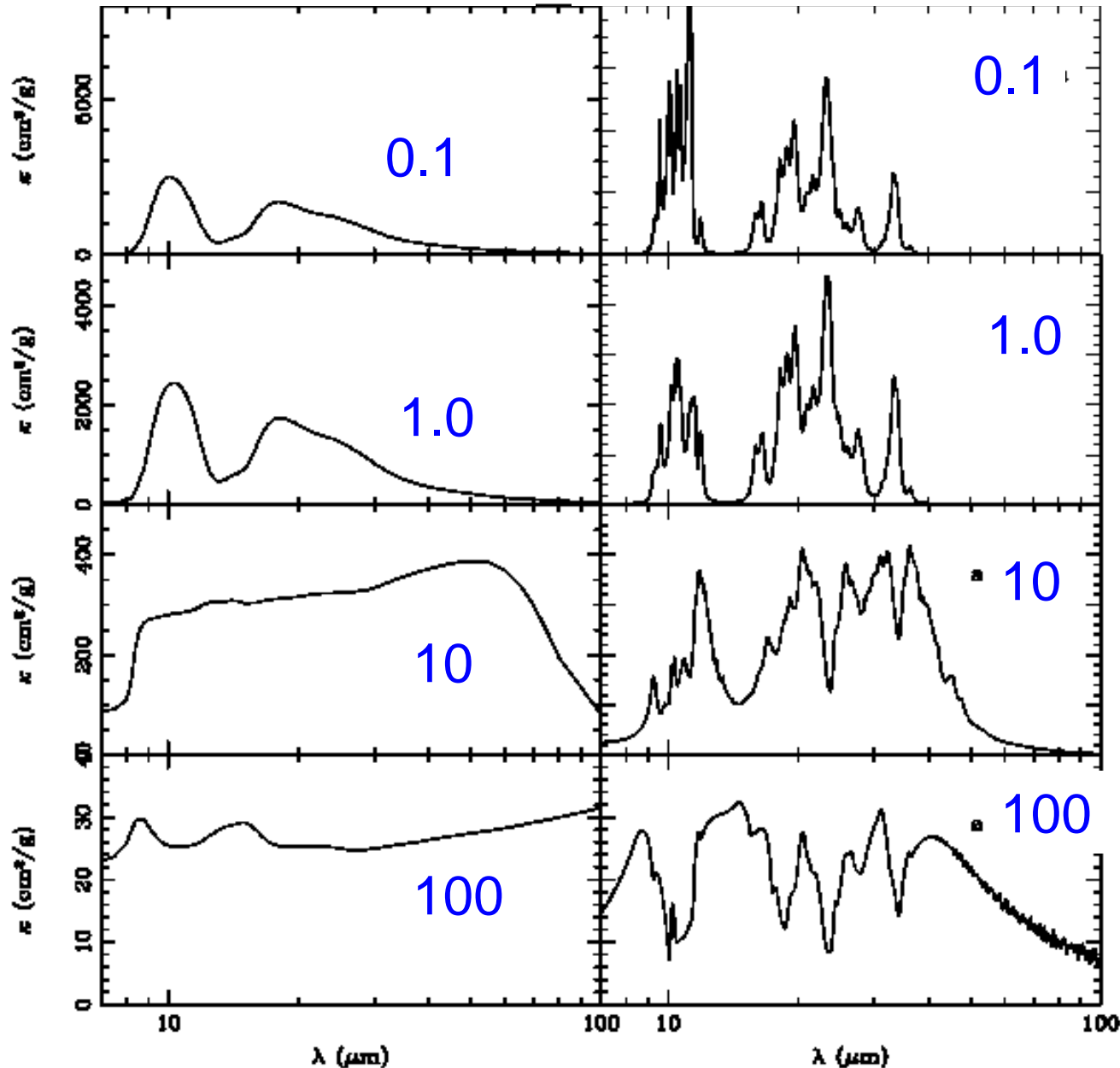
Weinberger et al 2004



- Silicate detected out to 15 AU
- Am/Cryst seems constant
- Should be detectable to 30AU, but not present: larger grains

Amorphous Olivine

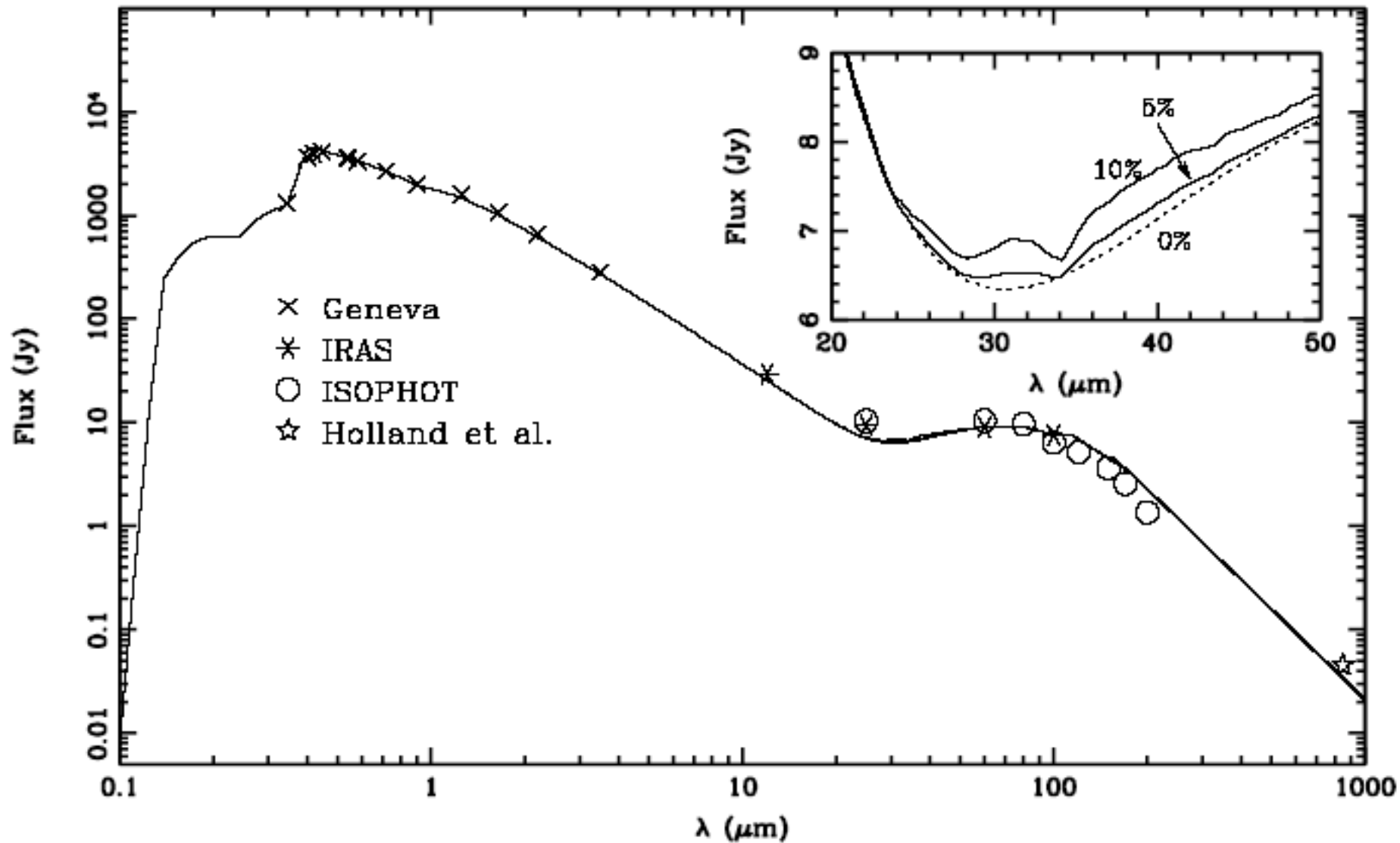
Crystalline Forsterite



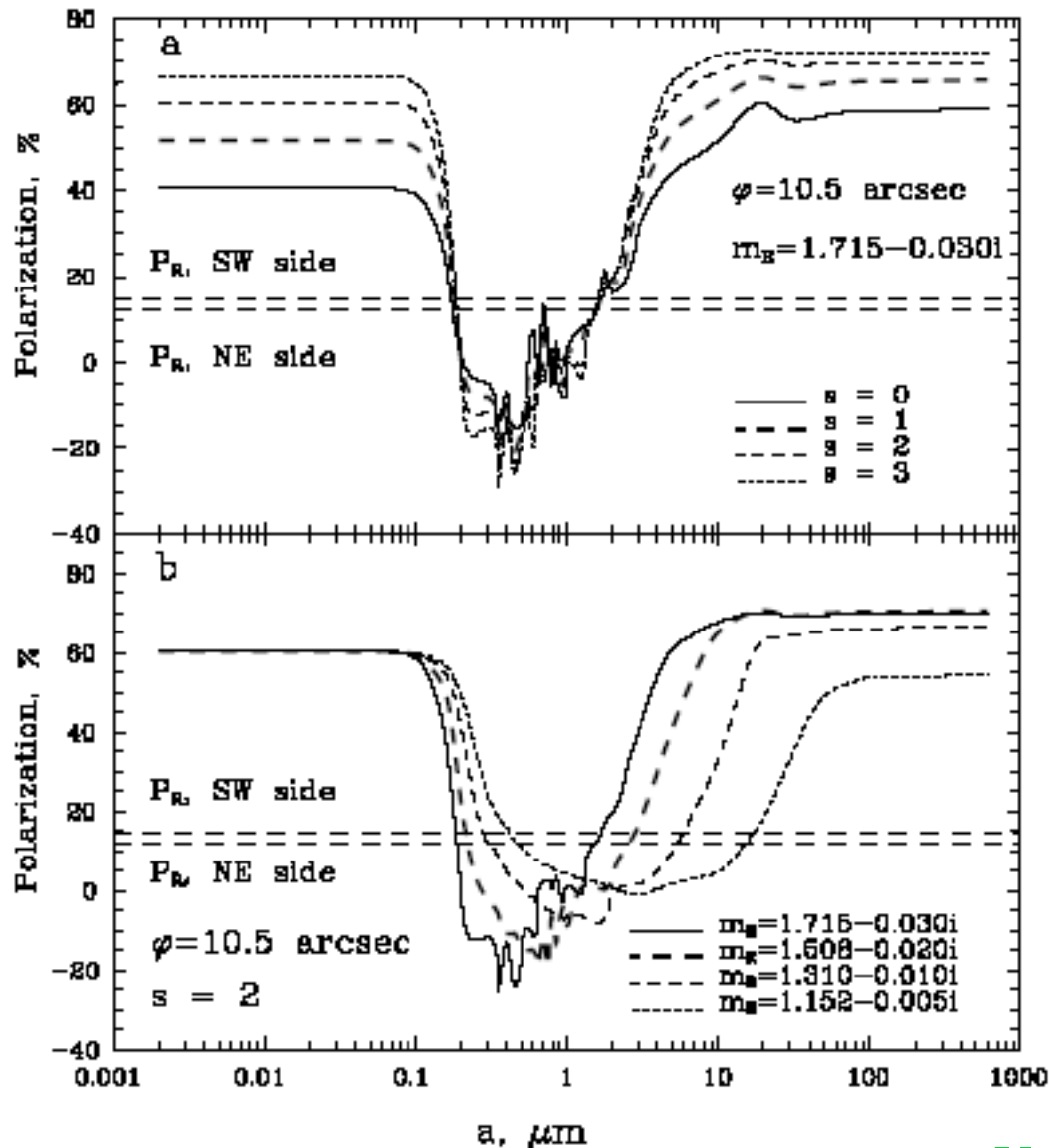
Spectroscopic  
diagnostic for  
large grains  
For compact  
grains,  
emission  
features go  
into  
absorption!

Min et al 2004

# Example calculation for Vega



# Polarimetry

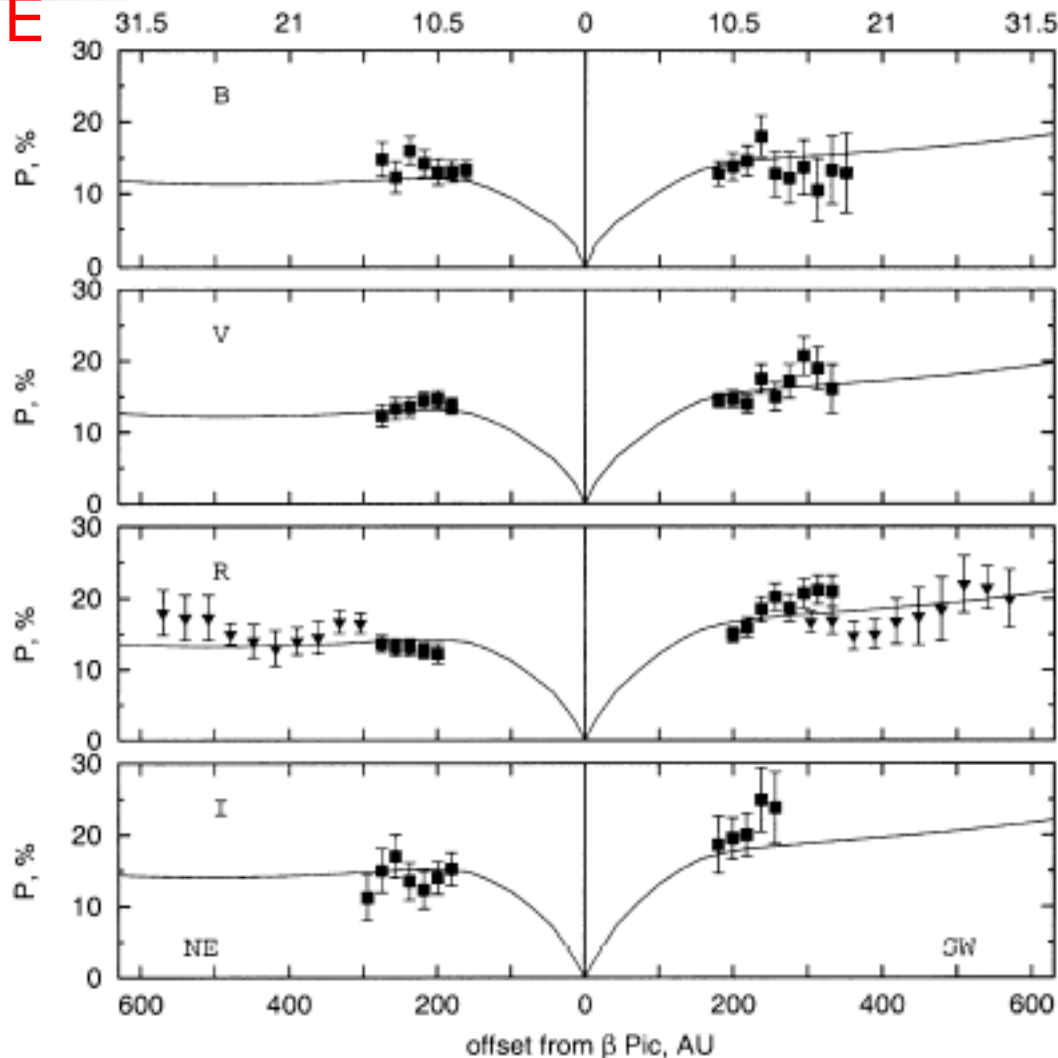


- Polarization depends on particle size and optical properties
- Can be used as additional constrain to determine dust properties
- Problem: Compute scattering properties of porous dust grains
- Currently only studies with effective medium calculations

Krivova et al 2000

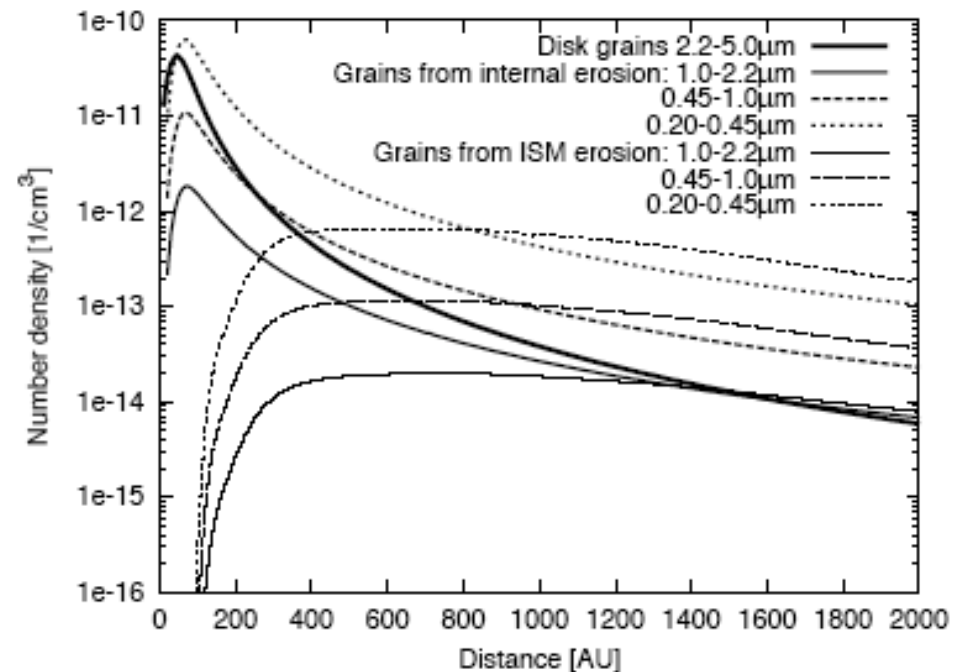
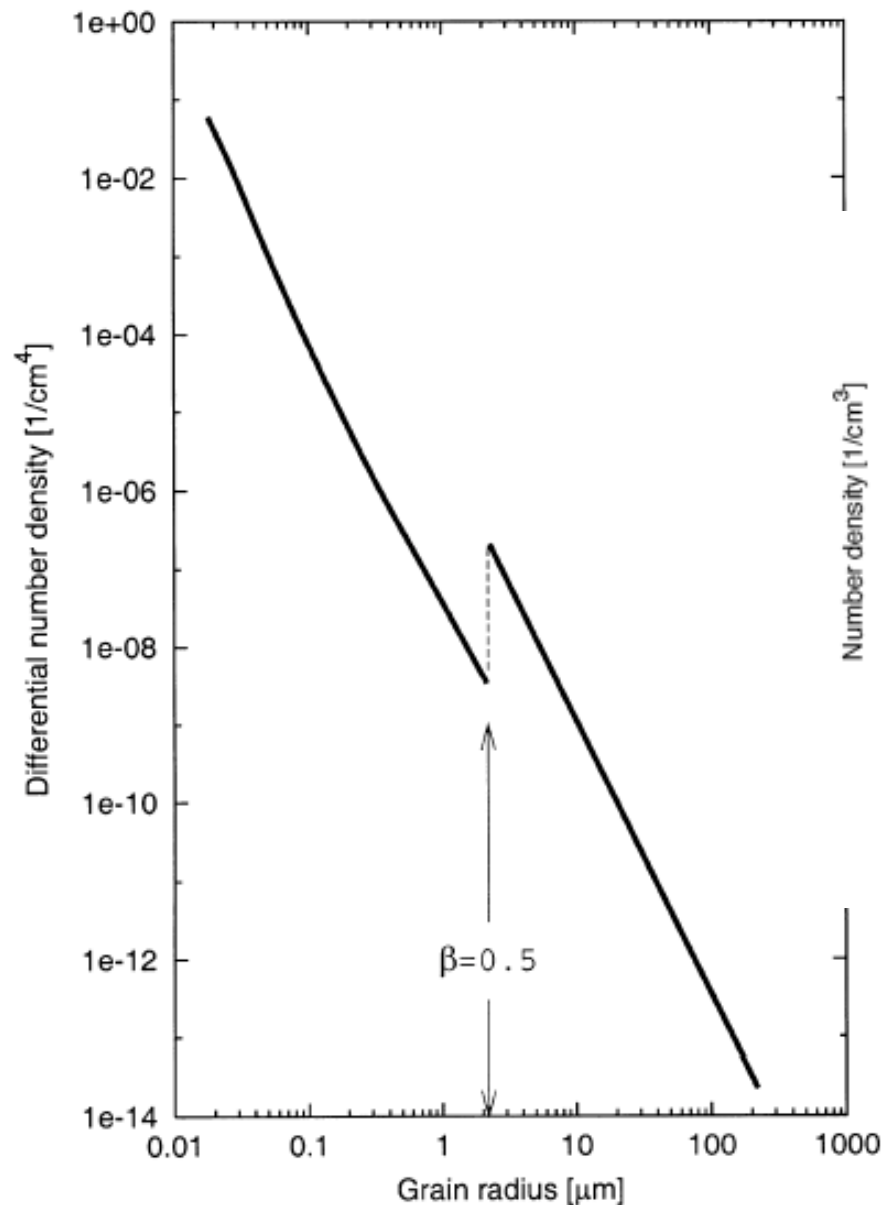
SW

NE



- Fits require large grains ( $>10$   $\mu\text{m}$ )
- Color dependence requires also the presence of small grains, but less than extrapolated from collisional equilibrium  $f(a) \sim a^{-3.5}$
- Additional small grains in NE wing, from collisions with ISM grains

# Modified collisional size distribution





# Conclusions I

- Dust grains in Debris disks are probably porous, cometary IDP-like grains.
- They contain silicates with moderate crystallinity fraction
- Crystallinity seems to be higher in inner regions
- Typical grain sizes are few to hundreds of microns
- Small grains (0.1 micron) are present in the more massive disks, where collisional evolution produces the grains quickly enough.

## Conclusions II

- Information about dust properties in Vega-like disks is sparse, mainly because the the main tool, spectroscopy is difficult to apply.
- Pure SED fits are not unique and leave many questions about grain properties.
- Better results can be obtained by fitting images and spatially resolved polarimetry at the same time.
- There is a spectroscopic diagnostic for large crystalline grains. Look for it!
- Need detailed optical properties for large porous particles, better than Effective Medium Theory

Acknowledgement: Thanks to Mike Meyer for some pointers to the SST results.